RECORDS AND RESEARCH IN ENGINEERING AND INDUSTRIAL SCIENCE

By the same author

RAILWAYS AND ROADS IN PIONEER DEVELOPMENT OVERSEAS: A Study of their Comparative Economics.
(*P. S. King & Son Ltd.*)

RECORDS AND RESEARCH IN ENGINEERING AND INDUSTRIAL SCIENCE

A Guide to the Sources, Processing and Storekeeping of Technical Knowledge
With a Chapter on Translating

By

J. EDWIN HOLMSTROM

B.Sc.(Eng'g.), Ph.D.(Econ.), A.C.G.I., A.M.I.C.E.

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PREFACE TO THE FIRST EDITION

THE aim of this book is to teach the remarkable and stimulating fact that the whole of knowledge, except what is purposely kept secret, is available for everyone to use. It is true, of course, that no individual can assimilate and remember more than an infinitesimal part of it; but what matters is not so much that knowledge should be "known" as that it should be drawn upon and applied. A man who knew an encyclopædia by heart would not on that account be of greater value to his fellows than one who merely had the volumes beside him; the governing consideration in either case being whether he was educated—in the widest sense—to make use of what was in them.

It is important that everyone who uses technical knowledge in his work, whether for immediate application to engineering or industrial practice or as raw material for new knowledge he is himself creating, should appreciate that provided he is master of the fundamentals the sources open to him are unbounded. Reports and other publications, translations, abstracts, indexes, libraries and institutions of many kinds exist to bring within his reach all that has been won by others throughout the world, for him to use, combine and develop at his will.

To serve as a guide to these resources; to promote their improvement and efficient working; to inform those engaged at the frontiers of knowledge, and on its lines of communication, of one another's functions; to inspire the practical man with a sense of that communism of the

intellect which is the beneficent glory of science; will be the object of these pages.

The illustrative examples have been borrowed from as wide a field as possible, and I have tried to combine a readable account of how technical science is organised with the presentation of a useful series of clues to where detailed and specific information may be sought, hoping that the profusion of references and cross-references needed for the latter object has not too much interfered with the attainment of the former.

It remains to add that the book was in the press when the outbreak of war forced most of the organisations mentioned to modify their activities, but it has been thought best to leave the text unaltered.

J. EDWIN HOLMSTROM

PREFACE TO THE SECOND EDITION

STOCKS of the first edition became exhausted early in the war but shortage of paper has prevented reprinting until now. The opportunity has been taken to carry out a fairly extensive revision which has lengthened the book by an aggregate of 64 pages of more recent references, in the hope that it will be useful for the period of post-war reconstruction. The sections relating to International, Imperial and Foreign Organisations for research have been expanded to form a short separate chapter which later it may be possible to amplify further.

J. E. H.

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All the organisations named have their headquarters in London, where their addresses may be found in the Telephone Directory, unless another place is named.

All non-periodical publications cited are Government publications issued through His Majesty's Stationery Office, London and branches, unless a private publisher is mentioned.

CHAPTER ONE

THE NATURE AND METHODS OF TECHNICAL SCIENCE

INTRODUCTION

TECHNICAL knowledge, the subject of this book, may be defined as the faculty which enables an engineer or an industrial chemist, physicist or metallurgist to do work which a man not so equipped cannot do.

Until a few generations ago all knowledge of this kind was empirical and traditional. Engineering and manufacture were carried on in certain ways rather than in others simply because that was the custom : improvements when introduced remained a matter of trial and error until in the course of time the failures ceased to be repeated and the fittest methods survived, but no background of scientific understanding had yet been pieced together against which their success or failure could be explained and utilised in deliberate and purposeful striving after progress.

Moreover, until the development of technical literature and " documentation " such knowledge resembled manual skill in that it could be transmitted only by personal instruction, that the opportunities for doing this depended on geographical propinquity, that unless so transmitted it died with its possessor, and that the range and variety of knowledge which an individual could bring to bear on any given task were, therefore, limited both by his inherent capacity and by the extent of his personal experience.

This is no longer so. Technical knowledge does not now depend only on its own past applications but can be extended, as and when required, by means of *ad hoc* experiment. Furthermore, in every field and at every stage of elaboration, it can be recorded—though imperfectly—on paper. It is in fact so recorded not only in the reports correspondence and drawings which circulate within every scientific and industrial establishment, but to the extent of some 750,000 articles and papers appearing in 14,000 technical and scientific journals every year in addition to about 14,000 books published during the same period. The whole of these vast resources—it is a stimulating fact and one of great social importance—is accessible for anyone possessed of the key to select, combine and apply as he wishes, whether for some immediate practical end or in the further synthesis of new knowledge which will be added in its turn to the stream. The exploitation of these ever-growing stores of knowledge is at present far from being fully realised and it will be a main purpose of this book to stress the importance of studying and improving the technique for doing so—a technique whose objective has been well defined [1] as "collective thinking with collective memory".

THE IMPORTANCE OF COLLATION

Knowledge is built up and is adapted to practical ends not only through the direct questioning of nature by experiment and observation but also through the collation—the placing side by side in new and fruitful conjunctions—of elements of knowledge which have already been ascertained and recorded. These elements are to science what bricks are to architecture.

[1] M. E. Schippers at 14th Conference, International Federation for Documentation, Oxford, 1938.

It is a strange fact, however, that while every textbook deals as a matter of course with the experimental technique appertaining to its subject, the principles of collative technique are scarcely ever systematically considered but are left for intuition to suggest. Too often the experimenter and the practical engineer are left unaware of the importance, equal to that of the laboratory, of the library, the bibliographical bureau with its indexes and abstracts, the study and the committee room.

Science is a living, organic thing, dependent for its vitality on a circulation of the blood which the appropriate organs enrich by their secretions and from which every member draws its sustenance. In the chart at the end of this book, to which frequent reference will henceforward be made, this is the idea intended to be suggested by the band marked "Documentation : Publications, libraries and bibliographical bureaux" which encircles those organs whose function is to produce primary knowledge, presently to be described. Should the circulation be sluggish, or its quality anæmic, the whole organism withers.

A programme of experimental research ought always to be preceded by a search of the literature to ascertain whether what is proposed has not already been done; but the economic importance of this principle is not well enough recognised and the machinery for giving effect to it has not been sufficiently thought out and developed, with the result that in almost every branch of applied science duplication and overlapping of experimental work continually occur.

Moreover, the mere recording and circulation of data effects nothing in itself, being but a first step towards their wider use. If those data are to be applied in engineering or industry, or if they are to be taken as the elements for the synthesis of further new knowledge, they need to be selected

from the mass, sifted, arranged and thought about. These operations—which have just as much right as experimental operations to be dignified by the name of " research "—may be performed by an individual worker or by a group of workers as will be considered later. Collative machinery, efficient or not, forms part of the internal organisation of all the knowledge-producing agencies described in Chapter Three which are indicated by the various rectangles in the middle of the endpaper chart ; it is the main *raison d'être* of those described in Chapter Four which are represented by the long rectangle across the bottom of the chart labelled " Learned societies and professional institutions ".

THE POOLING OF KNOWLEDGE FROM DIFFERENT SOURCES

This trend towards collectivisation in the procuring of knowledge, due to its becoming recordable and transmissible, has gone hand in hand with a trend towards collectivised methods in applying it to practical ends. A few decades ago accomplishment in engineering and in industry depended on the action of some single mastermind able to comprehend every detail of the job ; but nowadays we no longer depend, as of old, on giants, having discovered that still greater feats may be realised through the properly directed team work even of relatively mediocre individual minds. It is due to this fact that in every field the tempo of advancement has so greatly quickened.

As an arbitrarily chosen example of how any large undertaking depends on knowledge pooled from almost infinitely varied sources, consider the construction of a hydro-electric installation in the mountains, wherein a dam across the head of a valley serves to form an artificial lake in which water is accumulated up to a level enabling it to be run off through a

tunnel, and then through a pipeline down the mountain-side, into turbines coupled to dynamos for generating electric power which is used for some industrial process on the spot or is fed into the national supply grid. Every aspect and detail in the design and execution of that work was an application to practice of one or more scientific laws, more or less perfectly determined. In the first place the site and type of the dam were chosen by reference to geological considerations and to the attainment of a storage capacity sufficient for requirements despite seasonal fluctuations throughout the year; this involved a statistical study of rainfall records, taking account of the variation of rainfall with elevation and other factors. The surveying and setting out of the works were mathematical operations involving excursions into geodesy [1] (and thence, perhaps, even into astronomy) performed with instruments that were the product of optical knowledge. The foundations for the dam and the blasting of the tunnels involved the use of explosives, the manufacture of which had called for profound knowledge of a particular branch of industrial chemistry. Several of the constructional operations involved pile driving: the load-bearing capacity of piles is at present calculated by reference to certain not very satisfactory formulæ (laws which are as yet imperfectly understood), but research to clarify this matter is in hand. The design of the dam itself represents an application of the laws of statics which in their main principles are well understood, though many problems, connected, for instance, with the effect of temperature stresses in dams, still await full elucidation and are being actively studied all over the world. The dam was built of concrete, made with cement the quality and uni-

[1] Geodesy is surveying of such precision that the curvature of the earth has to be taken into account.

formity of which depends upon the understanding, by its manufacturers, of another branch of chemistry ; the mixing of this cement with the fine and coarse aggregate and water in order to obtain the strongest and densest concrete is a matter now much better understood than was the case thirty years ago and is becoming scientific. The design of the channel admitting water to the tunnel, the cross-section of the latter, the pipeline with its penstocks, surge chamber, safety devices and so on, all depended on knowledge of hydraulics. The joints between the successive lengths of pipe may, instead of by riveting, have been formed by the newer method of welding—a technique which is attaining reliability just as fast as the metallurgical laws affecting it can be worked out, for which reason papers are now continually appearing in journals and transactions of societies on such matters as the effect of the proportion of nitrogen in the weld metal on its strength, the behaviour of welded joints when subjected to alternating (or " fatigue ") stresses of different kinds, and so forth. The water turbines whereby the hydraulic is converted into mechanical power are beautiful examples of the application of precise knowledge—scientific laws—from many fields of study : not only hydraulic but also, for instance, metallurgical, in view of the enormous forces to which portions of the turbine runners are subject. Probably the hydraulic installation will be supplemented by either a steam or a Diesel-driven stand-by plant and this in its turn will have involved reference to thermo-dynamical science with as many ramifications, here alone, as any of the items already mentioned. The like is true of the electrical machinery, switchgear and transmission lines. If we assume that the electrical energy is intended for the conduct of some industrial process on the spot (such as the production of aluminium), we may begin

over again enumerating a whole sequence of considerations each of which is referable to a different department of science ; if, on the other hand, we assume that the current is fed into the grid for general distribution we are confronted with economic and social problems in which only a beginning has yet been made in the application of scientific methods.

Instead of considering this imaginary dam and power-plant we might have drawn an equally variegated picture of what is involved in the planning, construction or operation of a passenger liner, a new town, a factory, an engineering workshop, a bridge, a motor road, or anything which the reader's own interests may suggest to him. But enough has been said to bring out the fact that any such undertaking involves reference to a host of sciences far beyond the compass of any one human mind.

THE "ASYMPTOTIC" NATURE OF SCIENTIFIC ATTAINMENT

School courses in science are apt to give the beginner two wrong ideas : firstly, that science consists of parallel but quite separate "subjects"—chemistry (a business of glass tubing and cork borers) is one subject, physics (pins, mirrors and calorimeters) a second ; biology, which a few of the boys do, is a third, but they are taught by different masters at different times and have nothing to do with one another—and secondly, that "a science" is a finite collection of more or less memorisable facts about its particular "subject"—chemistry, for instance, means the contents of a certain book of 600 pages, and when you have got to page 400 you know two-thirds of chemistry.

It may just be worth while to warn the less experienced reader here against any carry-forward of these erroneous

ideas. The division of science into "subjects" is, of course, an arbitrary one which can be justified only by educational convenience and which ought never to be emphasised: for a practising scientist, even though he cannot be personally familiar with more than a small territory of science, must be prepared at any time to make excursions into collateral regions to find what he wants; must know, therefore, their main landmarks and enough of their languages to ask his way in them, as it is hoped this book may help him to do. Science is not a cut-and-dried body of knowledge which someone has collected once and for all: it is an attitude of mind, a way of finding out. Unless these facts are appreciated science degenerates into mere scholarship and its study has a narrowing instead of a broadening effect on the mind.

A corollary to these considerations is that every question scientifically answered gives riseto others. As an illustrative example take the air-conditioning of buildings in hot weather (see [26·1]). When this problem was first faced the most obvious and elementary thing to do to improve the conditions in a hot room seemed to be to filter and also renew the air occasionally, and the scientist proceeded to work out just how often this should be done as measured by the concentration of CO_2. But, it was found, the change must not be effected with too high a velocity of the air or people will suffer from the effects of draughts: hence a second problem, that of determining the optimum velocity of flow of the air. Next, since the air was too hot, and since the technique of cold storage for foodstuffs was already understood, why not cool the room in the same way as a cold store is cooled by surrounding it with refrigerated brine pipes? This was actually tried, in theatres, thirty years ago or more: but it was not satisfactory because air will not hold as much moisture when cold as when warm and the

excess moisture was deposited as dew, giving the unpleasant and dangerous effect of a cold damp cellar. Then—said Carrier, the inventor of air-conditioning as we now know it—instead of actually cooling the air much below the outside temperature let us obtain most of the cooling effect on the occupants by drying the air so as to make room in it, so to speak, to hold the moisture which people are ready to evaporate from their skins: this will cool them because of the latent heat of evaporation extracted from their bodies; and it is a physiological fact that each individual's rate of evaporation from his skin will adjust itself automatically so that those doing hard muscular work and those sitting still will both feel comfortable while neither will feel chilled. This, as the reader can test for himself in buildings so treated, is a great success: but even now the result is not perfect—even after obtaining optimum conditions of freshness, rate of air movement, temperature and humidity, it is still not possible artificially to reproduce at will all the physiological and psychological effects of, let us say, a perfect spring day. What, then, is missing? We do not know: some people think it may be the state of ionisation (electrical charging) of the atmosphere, and, if so, control over that will doubtless soon be forthcoming, after which some other factor still more subtle will be thought of to engage the ingenuity of inventors. Thus the goal of perfection is continually being approached but never reached—it is approached, as a mathematician would say, asymptotically.

SCIENTIFIC LAWS AND THEIR APPLICATION IN TECHNOLOGY

The terms "science" and "laws" used in the foregoing examples must now be explained.

Science means organised knowledge: knowledge deriving its value not from the mere accumulation of facts but from their arrangement in systems. An isolated empirical fact—for instance, the fact that the addition of lamp black to a rubber-like mixture increases the degree of toughness and the suitability for use in motor tyres—is not science, however useful it may be for some immediate application: but when it is juxtaposed with other pertinent facts—in this case those belonging to the chemistry and physics of the hydrocarbon polymers in general—and some systematic relationship is proved to subsist between them it becomes an accretion to science. Its value as such has no necessary relation to its applicability in industry.

Similarly, a law, in the scientific sense, is a statement of some proved recurrent relationship between the factors underlying and governing phenomena; and in the "exact" sciences a law, to be worthy of the name, must be expressible in mathematical terms. Laws are arrived at by first of all collecting and recording facts, then classifying these facts into series or sequences, then discovering some short formula which will enable the sequences of facts to be described in the most comprehensive and convenient way; finally by subjecting this formula (which until so tested is known as a hypothesis, not a law) to the proof of experiment.

The process is, in other words, an alternation of inductive reasoning (the discovery and proof of general propositions) with deductive reasoning (the application of general propositions once discovered to particular cases considered to be included within their scope): "A hypothesis is conceived and defined with all necessary exactitude; its logical consequences are ascertained by a deductive argument; these consequences are compared with the available observations; if these are completely in accord with the deductions, the

hypothesis is justified at least until fresh and more stringent observations are available." [1] The several methods which are available and logically acceptable for collecting observations are discussed in the final sections of this chapter.

These waves of alternate induction and deduction are superimposed, as it were, on a rising tide of which the general direction is inductive : a heaping up of a vast swell of generalisations which constitutes scientific knowledge as a whole and is represented figuratively at the top of the chart which forms the endpaper of this book.

Until recently the motive for heaping up scientific generalisations in this way was purely philosophical : civilised man confronted with a universe of random phenomena has felt an urge to tidy them up by arranging them in patterns. A century or so ago it began to be realised, however—at first in only a few fields of enterprise, later, at an increasing rate, in almost all—that the accumulation of proved and organised knowledge had an economic value, because it could be used as a take-off for flights of mainly deductive reasoning to explain the action of structures, machines and technical processes and to point the way to the attainment of practical objectives in engineering and industry.

A hundred or even fifty years ago the making of iron, glass, bricks, explosives, printing ink, or what you will, depended on series of processes very largely empirical. Materials were selected or rejected by eye ; their proportioning was done in the roughest way ; nobody thought of thermometers, pressure-gauges or hydrometers ; analysis or inspection in the modern sense of the words were unknown ; the stage reached in a reaction was judged from its appearance ; the duration of successive operations and the time

[1] R. A. Fisher : *Statistical Methods for Research Workers.* (Edinburgh and London : Oliver & Boyd, 6th Edn., 1938.)

and manner of the addition of ingredients were regulated by instinct and tradition.

Some forms of production, even so sensitive a chemico-physical operation as the mixing of concrete on an engineering job, are still commonly carried on in this way ; and it would be a distortion of the truth not to recognise that in the hands of experienced craftsmen doing what they have done all their lives (as well as their fathers before them) the quality of the resulting product may be excellent—better, frequently, than that of misapplied or imperfectly understood science.

But rule of thumb breaks down when some change occurs in the conditions to which the operator is accustomed ; a change, perhaps, in the materials available, or a need for a different product or for a greater variety of products to meet a shift in the demand. Wherever this is liable to happen rule of thumb cannot compete commercially with the modern principle of working out an explanation of every process in terms of scientific laws ; of obtaining in this way a clear understanding of how changes in ingredients, temperature, pressure and other conditions interplay with one another ; of formulating practical objectives in the same precise terms, and of controlling instrumentally every part of the process so as to ensure optimal conditions in accordance with those objectives.

This fact has now won general recognition, and empiricism —the propensity, as it were, of the less enlightened industrialist to shy at the expense of building up the mound of generalised knowledge in our diagram, preferring to take a short cut by tunnelling through it direct from specific items of knowledge to their more obvious applications—is discredited to the extent that business men in this country, individually and collectively, in fact deem it worth their

while to subsidise scientists with some millions of pounds a year, rightly expecting to be recouped by a continual increase in the range and efficiency of productive processes.

Naturally enough this financial support of science by industry is biased in favour of those activities whose material interest is more directly apparent : in the terms of our end-plate chart the business man is readier to contribute towards, or to organise in his own works, research on the "deductive" downward slope leading straight from existing generalisations to objectives which can be formulated commercially, than "inductive" research which is in the nature of an overhead charge on society as a whole. Science cannot, therefore, be financed by industry alone. As Siemens said sixty years ago when urging the foundation of the German prototype of our National Physical Laboratory,[1] "whether or not the recognition of a new scientific fact has a practical application cannot as a rule be determined until that fact has been systematically and completely investigated ; that is, often after an appreciable lapse of time. For this reason scientific progress must not be made dependent on material interests."

To put this in another way, "pure" as distinct from "applied" research is an act of faith. But over and over again such faith has been justified in the utilitarian sense and work long pursued for its intrinsic attraction alone has turned out, perhaps many years afterwards, to be exactly what was needed in the pursuit of some economically valuable purpose. "The history of applied science has proved"—remarks one of its greatest exponents[98.2]—"that fundamental research is the lifeblood of industrial progress and that the ideas which lead to spectacular advances spring

[1] The Physikalisch-Technische Reichsanstalt: Fifty years of progress. *Nature*, 26 Feb. 1938, pp. 352–4.

from it. As Sir J. J. Thomson once said, 'Research in applied science leads to improvements but research in pure science to revolutions.'" The highly mathematical enquiries into molecular physics which led to the development of the thermionic valve, on which broadcasting as well as long-distance telephony and many other commonplaces of present-day life depend, may be cited as one out of many illustrations of the point.

CONTROLLED EXPERIMENT

The building-up of scientific knowledge begins, as already explained on page 10, with the collection of observations. Science supposes (for everyday purposes, at any rate) that everything which happens has a cause, and the object of such observations is to be able to relate the happenings to their causes. In doing this it is necessary to make sure that the relationship between cause and effect as apparently observed has not in fact been distorted by the operation of causes additional to those consciously being studied ; or if it has been so distorted it is necessary to understand the nature and magnitude of the distortion and to make allowance accordingly.

There are two ways of collecting observations so as to guarantee this condition : the method of controlled experiment which is characteristic of the physical sciences, and the method of controlled sampling, or statistics, which is a necessary adjunct to the first named in the physical sciences in order to derive valid conclusions from groups of measurements differing from one another by reason of unavoidable observational errors, and which is the only available procedure in those departments of knowledge, such as the social sciences, where phenomena cannot be manufactured to order.

The underlying principle of the controlled experiment consists simply in taking precautions, while studying the relationship between any two variables, to ensure that any other variables which might enter into play at the same time as these, and which might influence them, are either kept constant throughout or are measured and allowed for. Thus in the schoolboy experiment of confirming Boyle's Law that the volume of a gas varies inversely as the pressure, it is necessary to make sure that no change in temperature occurs during the period of the experiment which would confuse the issue ; but if Charles's Law connecting the volume of a gas with its temperature is already known the temperature can be allowed to vary and a correction applied.

In every laboratory, devices are invented for increasing the range and convenience of application of the principle of the controlled experiment. For instance, in studying the behaviour of metals and paints as regards corrosion and weathering, exposure to the atmosphere under ordinary conditions of use takes too long and gives no guarantee of equal treatment to different specimens : "accelerated tests" are therefore standardised, in which specimens are mechanically dipped in acid, dried, exposed to light, etc., for definite periods ; they are periodically weighed and examined and the rate of attack can be plotted on a time base to allow of comparisons. Similarly, at the Building Research Station, Garston, there is an artificial weathering machine for the investigation of surface finishes on concrete by exposing specimens to smoke, water-spray, cooling and heating in succession ; and at the Road Research Laboratory, Harmondsworth, there are machines for testing and comparing road-surfacing materials under the separate or combined action of traffic and rain, by laying them in a circular track round which runs a heavy, remote-controlled, electrically driven

vehicle guided by a radial arm, and on to which water can be sprayed.

In any such case it is necessary to make occasional comparisons between specimens subjected to the artificial tests and specimens of the same kind exposed to ordinary conditions—known as "controls"—in order to relate the time scale of the one to that of the other and enable valid inferences to be drawn from the results of the accelerated or artificial tests.

Another valuable experimental device, successfully adopted in research relating to the design of ships and aircraft and in certain branches of civil engineering such as hydraulics, is the use of small-scale models. Thus designs of ships' hulls are reproduced as wax models from 10 to 15 feet long which are floated and towed in a tank several hundred feet in length by means of a moving bridge provided with instruments to measure and record accurately the forces and other variables involved, and corresponding methods are applied in the study of aeronautics by means of small-scale models of aircraft suspended in wind tunnels.[1] In the case of railway and road vehicles a large proportion of the resistance to motion is aerodynamical in character, as in aircraft, but its study is complicated by the proximity and relationship of the underside of the carriage to the track which alters these conditions to an important extent; experiments in which a model vehicle is suspended stationary in an air tunnel over a rapidly moving endless belt to represent the relative motion between it and the track have not proved entirely

[1] The equipment both for ships and aircraft is described and illustrated in the booklet on the National Physical Laboratory mentioned here on page 103, and there is a longer, well-illustrated account of the former in the reprint of a lecture to students by J. L. Kent: The work of the William Froude Laboratory and its use in ship design. *Trans. Inst. Marine Engrs.*, Vol. 46 (1934–5), pp. 297–304.

satisfactory, and experiments on models of vehicles have been made, in Italy, by towing them under water in a ship-testing tank and applying a correction to the results to take account of the difference between the Reynolds Number (a figure which depends on viscosity and density) of the water and of the air respectively.[1]

The hydraulic problems which call for solution in schemes for river and harbour engineering involving the effects of tide and currents on erosion and silting can be worked out by controlled experiments on models. The existing bed of the river or estuary to be studied is modelled in sand to a scale of, say, 1 in 10,000 horizontally and 1 in 100 vertically, the whole being given the appropriate longitudinal slopes and contained (as a rule) in a wooden tray at table level which fills a large room. A current of water is poured through the model representing the natural stream and the effects of tides may be reproduced by suitable machinery, the proportions being so calculated that the effect of a complete tidal cycle in nature is represented in the model every few minutes and the cumulative result of many years of tidal or other currents can be seen, and measured to scale, in the course of a few hours. Models of engineering works under consideration are incorporated in or removed from their proposed surroundings at will, enabling their effects to be studied and accurately predicted.[2]

[1] *Eng. Abs.*, No. 28, Jan. 1938, Sec. 2.

[2] For an attractive account of these matters see *Hydraulic Laboratory Practice* (New York: Am. Soc. Mech. E., 1929), edited by J. R. Freeman, which is an annotated translation of a German book. Professor A. H. Gibson's *Report on the Construction and Operation of a Tidal Model of the Severn Estuary* (H.M.S.O., 1933) may also be read as a general introduction to the subject, and the present writer contributed a short article based on these and other works in *Civil Engineering*, Vol. 29, Nov. 1934, pp. 374–6.

The correlation between results as measured in such a model and as afterwards found to occur in the full size is beautifully exact, involving a mathematical technique based on what is known as the principle of hydrodynamical similarity which originated in Reynolds's studies in connection with the Manchester Ship Canal, first published in 1888.

CONTROLLED SAMPLING

For some purposes an alternative and for others a necessary adjunct to controlled experiment is the science of statistics; a term which connotes a great deal more than the mere tabulation of figures which its popular usage suggests.

Whereas, as already explained, the experimentalist proceeds by analysing a phenomenon into all its component causes and keeping these under control while observing the result of making each to vary in turn, the statistician lets them all vary together but scrutinises his observations in the light of a mathematical technique which enables him to tell, from the relations between them, just how fair a sample they represent of the results that would be obtained if no other causes were operative than those in which he is interested.

The need or otherwise for attention to the matter of "sampling" of observations may be illustrated in a digression. A gas, according to the kinetic theory, consists of a swarm of innumerable molecules flying rapidly to and fro with velocities which depend on the temperature, and colliding millions of times a second with one another and the walls of the containing vessel. If, keeping the temperature unaltered, we crowd them into half the previous amount of space, any given area of the wall will be struck by flying molecules twice as frequently and the pressure, we say, is doubled—intensity of pressure being our name for a force

which is proportional to the number of flying molecules impinging each second on unit area of the opening to a pressure gauge inserted through the wall of the vessel. In this instance no question arises of calculating whether the number of impacts registered is large enough to give a fair average because the opening is so enormous, compared with the spacing of the molecules, that we obtain a steady reading on the gauge no matter where we insert it and regardless of how long or short a time it remains exposed to the bombardment.

In many other kinds of physical measurements the same thing is true. Thus the interlocking effect of the crystals which hold a piece of steel together probably varies from one small group of crystals to another, but the strength of one square inch cross-section of a bar as measured in a testing-machine represents the average of so many thousands of crystal interlocks that it is practically the same as that of any other square inch taken from the same ingot. The occurrence of some relatively weak and some relatively strong contacts is a matter of *chance*—something we cannot account for—but the " population " (as a statistician would say) of these crystals in a test bar is so numerous that we measure the average automatically.[1]

In regard to many other kinds of observations this is not so. Manufactured products, for instance, are usually required to comply with certain standards of quality for which certain forms of test are specified, but where the tests are such as to destroy the articles tested it is obvious they can be applied to only a fraction of the total numbers

[1] Professor Max Born: Statistical laws of nature (29th Kelvin Lecture), *Journ. I.E.E.*, Vol. 83, Dec. 1938, pp. 802–13, explains in an interesting way what is meant by chance and probability, and how physical laws are really statistical laws disguised by the coarseness of our methods of measurement.

produced. In any case, whatever the number of articles we choose to test, we are obliged to try them one by one : it is as if we had to count the number of impacts per second on an area corresponding to a single molecule of the gas, or to measure the strength of the bond between only one pair of crystals in the steel. This being so, we all know it is unsafe to assume that a single sample taken from a large group will be truly representative of the whole, and that we can get a better idea of how closely similar the individuals are to one another or how widely different, by increasing the number of samples.

Suppose, now, we are manufacturers of electric lamps which we subject to certain tests of efficiency and have devised a numerical scale for expressing the respective scores of the lamps tested. Suppose that, out of 500 lamps tested, 300 lamps give scores between 99 and 100 and the great majority of the remainder give scores about equally balanced below and above these values, but an occasional lamp is much less or much more efficient than the others. It will seem natural to assume, then, that the average score, if we were able to test every single lamp produced in the same physical circumstances, would work out somewhere near 100.

But just how certain can we be of this ? Should we be entitled to feel more certain if we were to test another hundred lamps, or another two hundred ? Would it be safe for us to offer to replace, free of charge, any lamp which scored less than, say, 98 when subjected to the tests ?

To such questions as these, statistical technique enables precise answers to be given. In dealing with this problem a statistician would first make sure whether there were any reason to suspect lack of uniformity in the materials or methods used in making the lamps and, if so, would

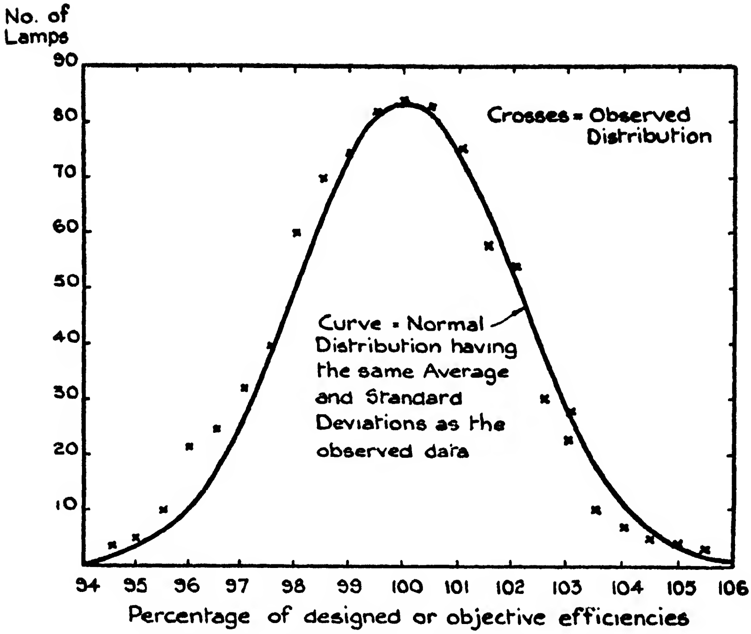

FIG. I. TEST RESULTS FROM ELECTRIC LAMPS.

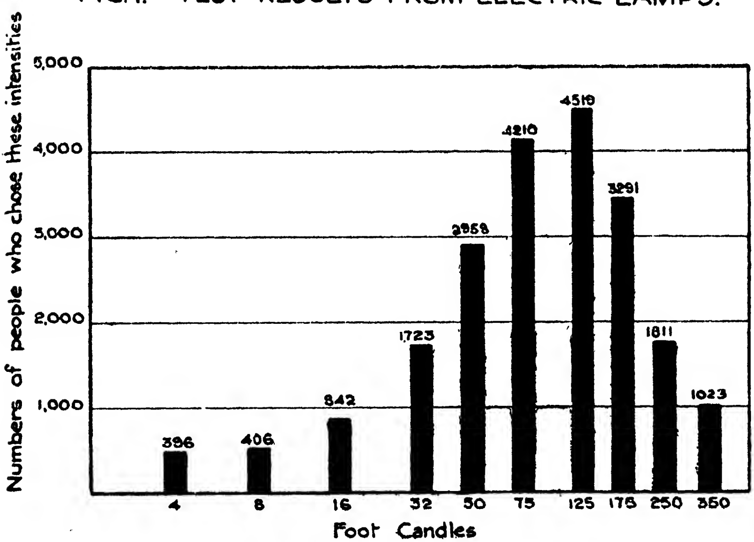

FIG. 2. PREFERRED INTENSITIES OF LIGHTING.

divide them into separate lots accordingly. From each lot he would take, say, several thousand lamps at random ("randomness" being ensured by special precautions) and would have these tested. He might either treat each test score as a separate unit or, preferably in such a case as this, treat the mean of every 25 (or other convenient

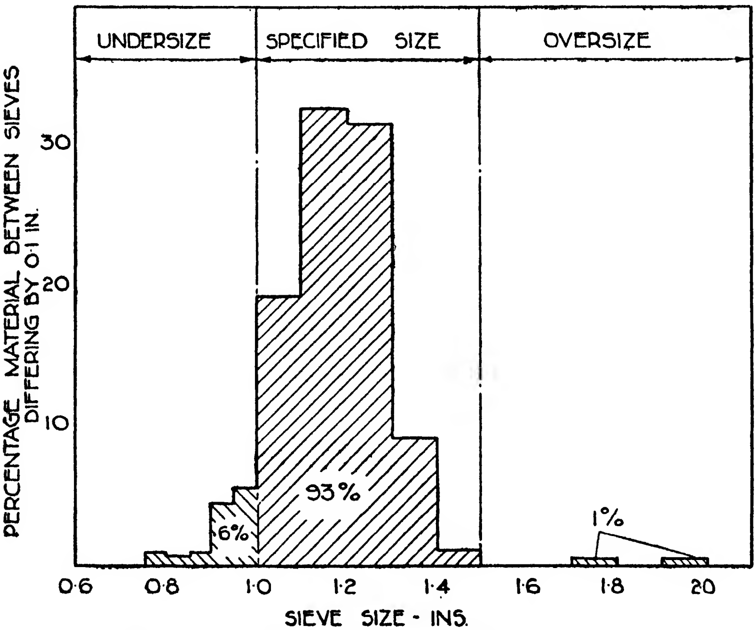

FIG. 3. DISTRIBUTION OF SIZE IN NOMINALLY SINGLE-SIZED ROAD STONE.

number of) scores as a composite unit of the "population" he is investigating. These data he would proceed to plot after the manner of Fig. 1, in which the scores obtained in testing the lamps are measured horizontally and the numbers of lamps corresponding to each score are measured vertically. He would then perceive, from the shape of the curve, that the scores obtained from these tests belonged

to the large class of phenomena which conform to what is known as a Gaussian or *normal frequency distribution*. Perceiving this, he would calculate—

(1) the arithmetic mean of all the observed values,
(2) hence the *deviation* or difference of each observed value from the mean,
(3) hence the *standard deviation* for this particular sample equal to the square root of the mean of the squares of the deviations of all the observed values.

By reference to published tables he would then be able to calculate the standard deviation for the whole "population", and hence to plot the curve in the theoretically perfect form it would have if the number of values available were infinitely large, but fitting the observed values as closely as possible. This would enable him to make such statements as the following:

Based on samples of 25 lamps, which is the test quantity defined in the British Standard Specification, and on the fact that the 100% point in the diagram (Fig. 1) is the factory objective efficiency—

(1) The chance that the mean efficiency of a random sample of 25 lamps will differ by more than 1% from the factory objective is 0·017, or, if 60 persons purchase at random batches of 25 lamps, only one person would be expected to find his average efficiency differ by more than 1% from the factory objective.

(2) The chance that at least one lamp in a sample of 25 will have an efficiency 6% less than the factory objective is 0·052 or, referring again to the 60 purchases, it would be expected that only three would find that their 25 lamps contained at least one whose efficiency was 6% below factory efficiency.

(This example is taken from the paper by B. P. Dudding quoted on page 28 by kind permission of the author, who has been good enough to amplify it in correspondence. It is to be noted that the lamps in question were tested

in 1934 and the results are not, therefore, representative of to-day.)

The normal frequency distribution is far from being the only kind of relationship between quantities which statisticians have taught other scientists to understand and utilise. It is, however, the distribution which holds good when the variable we are plotting represents the sum (or average) of a great number of elementary variables independent of one another or nearly so, and this happens to be true of many biological, psychological, social and meteorological phenomena. It is true, for instance, of people's independent judgments as to what constitutes the most comfortable intensity of lighting for reading a newspaper. This is shown in Fig. 2 which gives the results of testing 21,179 members of the public in a demonstration arranged at the Lighting Service Bureau of the Electric Lamp Manufacturers' Association in London, in the course of which each individual was invited to sit down and, while reading, adjust a regulator of the illumination so as to obtain the particular intensity that he, in his absolutely free judgment, preferred. The curve of distribution, it will be seen, conforms closely to the shape of the "normal frequency" law (though with considerable "skewness"), the largest group of people being those who chose an intensity of 125 foot-candles [1] and the numbers who preferred it brighter or less bright being in accordance with the curve.

A less perfect example of the normal frequency distribution is reproduced in Fig. 3. In connection with experiments on road material it was required to study the distribution

[1] Actually the intensity of illumination in an average room or office is seldom higher than 15 to 25 foot-candles. This diagram is reproduced, by permission, from *The Science of Seeing* (Electric Illumination Handbook No. 1A), E.L.M.A. Lighting Service Bureau.

of the actual sizes among pieces of stone supplied under contract as nominally "single-sized" material to pass through a 1½-inch ring. It will be seen that the diagram, which shows the percentages of the total weight of material which could be shaken through successive sizes of sieves each 0·1 inch larger than the other, follows an approximation to the normal frequency distribution. This particular sample contained an unusually high percentage (93 per cent) of material between the specified limits of 1½-inch and 1-inch sieves. By studying such results as this it is concluded, for instance, that the different types of screening-plant vary considerably in efficiency; that the rate of feed through the screen appears to be the most important factor, but that the consistency of feed and the shape of the stone (whether cubical or flaky) and many other conditions connected with screen design enter into the problem. The example serves to illustrate how the results of statistical examination may provide the key to questions of technical design.[1]

An important application of statistical technique is found in the inference of valid results from "scattered" readings obtained in experimental measurements or in surveying. As anyone who has tried it is aware, when a particular determination of this kind is repeated several times over with a view to greater accuracy the readings obtained on the instrument are not, as a rule, exactly the same each time, even though there be no question of "mistake" and all causes of "systematic" errors due to physical causes affecting the measurement have been eliminated. The question which then arises as to how many times each reading ought to be repeated, and what figure should be taken to represent the true quantity for use in subsequent calculations, is exactly similar

[1] Reproduced by permission of the Controller of H.M. Stationery Office from *Report of the Road Research Board*, 1938, p. 23.

to the problem of sampling the electric lamps described above and can be solved by the same means. This branch of statistics is known as the *theory of errors.*

Another branch useful to the experimenter is the *theory of correlation* which, when he has discovered that one factor entering into an experiment seems to depend on another factor, enables him to work out and express quantitatively the nature and closeness of this dependence. The degree of association is shown numerically by the " coefficient of correlation " which is stated as a number lying between the limits of 1 and -1. A correlation coefficient of 1 indicates that there is perfect association between the two variables, the highest value of the one variable corresponding to the highest in the other, and vice versa. A correlation of -1 indicates that there is perfect inverse association between the two variables, the highest value in the one variable corresponding to the lowest in the other, and the lowest in the one corresponding to the highest in the other. Any degree of association falling short of perfection is given as a decimal fraction, either positive or negative. When the correlation coefficient is so large that its value is unlikely to have arisen through errors of sampling, the association between the two variables is said to be " significant ".[1]

An interesting example of a chain of correlations is mentioned in [187.1] : it appears that variations in the water levels of the Great Lakes in Central Africa are correlated with the 11-year sunspot cycle and perhaps also with rainfall

[1] Quoted from T. Bedford : *Modern Principles of Ventilation and Heating* (London : Lewis, 1937 ; three lectures) which exemplifies this in the correlation coefficients between " comfort votes " and instrumental readings which are the basis of design for air-conditioning installations to ensure comfort by controlling the interplay of temperature, humidity and rate of air movement.

in West Africa, which hydrologically is quite distinct ; also with human migrations on the southern borders of the Sahara, with the movements of locusts and with the food shortages which follow these a year later. Frequently the perception of correlations between variables such as these, which at first sight are not causally connected, opens the way to an advance in scientific knowledge.

It is, however, in the sociological field that statistical methods have been cultivated to greatest effect, for the reason that where no possibility exists of arranging a controlled experiment as a means of manufacturing data " to order " the only way to render the study scientific is to apply statistical methods to the analysis of data which have been produced by nature. It is impossible to imagine a more elusive complex of causes, motives and choices, from which controlled experiment is more completely ruled out, than that which governs the life, actions and contingencies of a human being : yet so completely random are these variations that when averaged for a large number of people they balance one another and make it possible to predict, with sufficient accuracy to enable assurance companies to be run at a profit, how many (though not, of course, which individuals) of each ten thousand people now alive will be still living in each year henceforward, how many will marry, and how many children they will have.

Similarly, the theory of probability can be used to provide a rational basis for a plant depreciation fund. This is among the industrial problems treated by graphical methods in A. C. Haskell : *Graphic Charts in Business.* (New York : Codex Book Co., 1928.)

Statistics is not an easy subject to master, but books are available which enable its principles to be applied in practice

without the need for more than elementary mathematical attainments. As introductions I can recommend an altogether admirable little book by L. H. C. Tippett: *Statistics* (Home University Library, 1943), and another in amusingly colloquial style by L. J. Holman: *Simplified Statistics* (London: Pitman, 1938). Going beyond these, the beginner may find it helpful to consult more than one book, since what at first appears forbidding may become clear when presented in another (not necessarily better) way. Professor Fisher's work, already quoted [11.1], is for the serious student, but the introductory chapter will be found readable and illuminating by others also. Other well-known books are G. U. Yule and M. G. Kendall: *An Introduction to the Theory of Statistics* (London: Griffin, 11th edn., 1937) and L. R. Connor: *Statistics in Theory and Practice* (London: Pitman, 3rd edn., 1938) in which the examples are mainly economic and sociological. Each of these works contains bibliographical references to yet others.

An excellent short exposition of "The application of statistical principles to industrial problems" may be found in a paper under that title by B. P. Dudding in *Jun. Inst. Engrs. Journal*, Vol. 46, March 1946, pp. 278–94. There are also an article on Quality Control by Sir Frank Gill appended to [83.2] and a 38-page book by E. H. Seely entitled *A First Guide to Quality Control for Engineers* (H.M.S.O., 1945) used by the Ministry of Supply Advisory Service on Quality Control. E. S. Pearson's *The Application of Statistical Methods to Industrial Standardisation and Quality Control* (London: British Standards Institution, 1935) is larger. *Sequential Analysis of Statistical Data* (London: Oxford Univ. Press, 1945) is an American official report describing a new method in which the size of the sample is not predetermined.

CONTROLLED GUESSWORK

It is a necessary part of the scientific method of arriving at truths (as described on page 10) to make guesses of what *may* be true and then to apply tests which will either confirm or disprove these guesses. A good analogy to this process is provided by what is known as "bracketing" in the direction of artillery fire. The same principle is applied in designing a bridge girder; that is, in calculating the dimensions to which the various members should be made in order that when under full load the intensity of stress in each member may come within certain limits depending on the material to be used. Part of the load to be allowed for (indeed, in a long bridge, the major part) will be the weight of the bridge itself: but this depends on the very dimensions which the designer is trying to decide. The escape from this vicious circle is by way of a guess. Aided either by his own experience or by the recorded experience of others, the designer knows that more or less similar bridges have been designed in the past weighing so many pounds per foot run: he assumes, tentatively, a likely figure for the new bridge, converts it into square inches cross-section of steel, tries out on his drawing-board how the components may best be arranged to give this area of cross-section in the proper positions and calculates the stresses due to dead, live and other loads which will occur in the bridge if so built. If these stress intensities work out within the desired limits, well and good; if not, the designer makes a different guess and tries again.

More complicated examples might be quoted (especially from the border region between technology and practical economics which is sometimes known as "commercial research") in which guesswork has to be used as a means of

filling the gaps between fragmentary and incomplete data. In such work two principles may be laid down :

(1) When a quantity has to be guessed it is safer instead of making one big guess to ask oneself how the total quantity is made up, make a separate guess of each component, and add or multiply the elemental guesses together as the case may be.

(2) When data cannot be checked as regards accuracy the next best thing is to check them as regards consistency. It sometimes happens that two independent sets of data bearing on a certain problem are available, both sets incomplete and doubtful but of such a kind that if they were complete and accurate they would enable a certain numerical result to be calculated by two different lines of approach. In such a case the procedure to follow is to fill in the gaps in the data with figures that *might* be true (even though there can be no check as to whether they are true) and to see whether, by persistent trial introducing any reasonable assumptions, it is possible to calculate the same result from both sets of starting-points. If this can be done without having to alter any of the individual data beyond their probable range of error, and without having to strain any of the assumptions beyond the limits of common sense, there is justification for regarding the data as mutually checked and the calculated result as a controlled guess.

Arbitrary guesswork without possibility of check is not admissible in science, but to recognise controlled guesswork —convergent approximation—of this kind as a forerunner or complement to controlled experiment and controlled sampling is simply to admit that the exercise of imagination sometimes forms the key to progress either in building up new knowledge or in applying science to practice.

COLLATION BY INDIVIDUAL INITIATIVE

New knowledge is built up by putting together primary data and turning them over in the mind against a background calculated to throw them into relief, such data being (1) already present in the mind of the knowledge-builder by reason of his past experience, or (2) gathered from the literature as discussed in Chapter Six of this book, or (3) manufactured *ad hoc* by Controlled Experiment, Controlled Sampling or Controlled Guesswork as explained in the preceding three sections.

Of these kinds of data those already registered in the memory are the most valuable, subject to their accuracy being checked before they are used, because their assembly into fruitful juxtapositions takes no time at all and occurs spontaneously, but methods are considered in Chapter Seven for treating data of types (2) and (3) in such a way that they shall be as nearly as possible as useful as those of type (1).

In any case it is the process of collation—or integration, if the term be preferred—of these primary elements of knowledge which creates knowledge properly so called. That process is essentially a personal one. Ingenious machines can be built to produce the primary data by taking and recording measurements, counting and calculating, analysing gases, initiating physical actions at pre-determined times or in pre-determined combinations of physical circumstances, or picking out particular kinds of card records from a collection (see page 281), but no machine can be devised which will originate new ideas. Nothing can do that but a suitably attuned human mind.

Ultimately, then—as organisers must never forget—the progress of science and of the applications of science depend

on the capacities of individual men and women, the subject here of Chapter Ten.

Much collative research is performed by independent individuals. It is open to any technical man to choose a subject (or, in the terminology of the next section, to formulate his own " terms of reference "—and alter them as often as he pleases), collect and arrange data thereon, think about them, reach conclusions, work them up into a paper or article or book, and offer it to an appropriate institution for discussion and incorporation in their proceedings or to an independent journal or publisher. But the effectiveness of the thought of individual minds can be increased by the mutual stimulus derivable from working in concert with other minds, and this is the object of the machinery outlined in the next two sections. Committees and conferences are poor substitutes, however, for the most effective and useful of all ways of exchanging ideas: informal conversation between two or three people who feel themselves in sympathy.[1] It is important when interviewing a stranger for technical information to do nothing that may give the proceedings a needlessly formal air: to produce a notebook may be fatal, whereas to jot down a few points on the back of an old envelope taken casually from one's pocket is a different matter, and all engineers regard it as a matter of course to cover such scraps of paper as may be within reach (or the tablecloth and menu card at meals) with sketches of their ideas.

[1] Where numerous personal contacts are important as sources of information it is convenient to keep track of them by means of two card indexes: one arranged under subjects giving the names of individuals to whom particular topics may be referred and the other containing a card for each person with his address and a record of dates, cross-references to correspondence, etc. The dual arrangement is necessary because a given subject may be referable to more than one person, while on the other hand a single person may be an authority on more than one subject.

Immediately after the conversation, while what has been said is still fresh in the memory, is the time to make complete notes.

COLLATION AIDED BY COMMITTEE

Collation is performed in many different ways by different agencies and if, for convenience of discussion, it is represented below as a succession of steps, the reader must not suppose for one moment that all of these are invariably gone through, or that they are necessarily taken in the order given.

This being understood, let us make a list of the full number of operations which may be involved in the production and issue of a report by, say, one of the engineering institutions on some question of professional interest which has been made the object of research under the direction of the appropriate committee :

(1) The whole process is initiated by the governing body of the institution concerned formulating the " terms of reference ", or questions which the committee are required to answer in the eventual report.

(2) The primary data on which to base the answers are collected, whether from experiments undertaken with that specific object or by searching the relevant literature, issuing questionnaires, etc., or by drawing upon the personal knowledge of the members of the committee, or by combining any or all of these sources.

(3) Someone embodies these data in the draft of a document. (This is dealt with in Chapter Eight.)

(4) The draft document is multiplied (in one of the ways discussed in Chapter Eight) and copies are distributed to members of the committee.

(5) It is discussed, criticised, amended and perhaps re-

written at meetings of the committee and is finally approved by them in a form for which they are prepared to accept collective responsibility.

(6) If the above-mentioned committee is subordinate to another, steps (4) and (5) are repeated in relation to the higher committee, and again in relation to the governing body of the society concerned if its constitution so requires. These higher authorities may decide to "adopt" the report in the form submitted to them, or may refer it back to the originating committee for reconsideration and re-submission.

(7) When the draft report has been adopted by the governing body of the institution it may—if such is the rule or custom—be printed privately and brought before a wider audience, such as a general meeting of all the members of the institution, for them to discuss before it is finally approved and published.

(8) Finally, it is printed and published as a permanent record which all may read (maybe with an account of the discussion appended to it) either as a separate document or in the "Journal", "Proceedings" or "Transactions" of the institution concerned.

Mutatis mutandis, and not taking it too literally, this description applies not only to the production of reports by professional institutions but to almost any kind of committee procedure, the emphasis to be laid on the various steps differing from one instance to another. Omitting steps (6) and (7) it applies, for instance, to a Royal Commission of Inquiry appointed by the Crown at the instance of Parliament, or to a Special Commission or Departmental Committee appointed by a Department of State—the first mentioned of these being distinguished not only by the eminence of the persons appointed to serve but by the fact that the commissioners are legally empowered to call and hear evidence (although

not on oath) and to demand any documents for examination. Another peculiarity is that not only the resulting report [1] but the evidence *in extenso*—questions and answers duly numbered—are printed and submitted to the Sovereign and to Parliament and afterwards published.

Committees which direct the performance of experimental research and consider reports thereon follow much the same procedure as is described above, omitting step (7) and, in the case of a confidential report or one intended only for internal circulation, step (8).

The chief value of a committee is as a sounding-board for whatever individual has the keenness, originality and driving power to bring new ideas before it by performing step (3) as above. That individual may be the chairman or one of the members or, as often as not, the secretary of the committee who even if not himself a member can influence it a great deal by the way he keeps the minutes, prepares the agenda and material for consideration, drafts forms of words to crystallise the discussion while a meeting is actually going on, and tactfully offers these to the chairman's attention. The all-important thing, whoever does it, is to *formulate the issues* as definitely as possible like the questions which a judge puts to a jury in his summing-up; failing this a committee is liable merely to talk round a subject without reaching conclusions. Unless someone is willing to "put up something to be shot at", as the phrase goes, a committee is useless; but given such willingness a committee with a good chairman and secretary provides the most effective

[1] These reports are often valuable and always authoritative sources of information. Instances of Royal Commissions which had a technical bearing were those on Sewage Disposal (1915), Mining Subsidence (1927), Land Drainage (1927), Safety in Coal Mines (1938). The Weir Committee on Main Line Electrification (1931) was even more technical.

known means for improving upon individual suggestion through systematic criticism of both matter and wording.

On the other hand committee work cannot in the nature of things be a quick method of arriving at results ; for, having due regard to the convenience of a number of men, all busy in different ways, there is a limit to the frequency with which meetings can be arranged. It follows that the best possible use must be made of the opportunity when a meeting does take place ; and this depends equally on the skill of the chairman and on the thoroughness and intelligence of the secretarial preparations.

Even so the rate of progress likely to be made is unpredictable. At one meeting a committee will swallow a lengthy document whole ; at another the members will fasten on to a single item and worry it, like playful terriers, for hours on end.

COLLATION AIDED BY DISCUSSION IN CONFERENCE

It is one of the main functions of the learned societies, professional institutions and international bodies mentioned in Chapters Four and Five to hold general meetings or conferences at which papers are "read" and discussion thereon is invited by any interested persons present, both the original paper and a record of the discussion, with the author's reply, being subsequently printed in permanent form. In this way the value of such a paper as a contribution to knowledge may be greatly enhanced, since the author in addition to having collated his own data provokes comparisons with the views and experiences of colleagues and provides a convenient occasion for their expression which might otherwise be wanting.

Most of the engineering and other professional institutions hold evening meetings for this purpose once a week or

once a fortnight throughout the winter. In most of them the practice now is to have the paper itself printed for private circulation enabling any member interested in its subject matter to obtain a copy beforehand and prepare his intended contribution to the discussion, and at the meeting only a synopsis of the paper is actually read, leaving the rest of the time for additional remarks by the author, showing of lantern-slides and discussion.

At conferences or symposia of many papers the *rapporteur* system is increasingly adopted : the papers are divided into groups according to subject matter and a leading exponent is appointed in reference to each group with the duty of drawing up a summary indicating the points of special interest and those on which the various authors agree or differ ; this summary or general report is read out at the meeting to give a start to the discussion and suggest questions which it would be useful to ventilate, and is afterwards published with the group of papers to which it belongs.

Usually, also, a statement of the conclusions reached by the conference as such is drafted by a committee and submitted for approval at a final meeting of the whole body. In this way the outcome of an important technical conference may be one or more bound volumes containing perhaps several thousand pages which constitute an up-to-date, representative and authoritative review of the subject which has been under discussion.

Apart from this, the informal personal contacts and discussions which originate at a conference extending over several days are valuable, and to encourage them it is important that the social side should be well organised. To facilitate identification and the striking up of acquaintances among members of a conference it is a common

practice to provide them with badges bearing their names which they are invited to wear on their lapels : a better plan is to let them wear numbers one inch high which not only can be read at much longer range but, by reference to a list, indicate the wearer's title and origin as well as his name.

At most international conferences the written and the spoken contributions are accepted in English, French or German and provision is made for translation and interpretation into the other two of these languages—a matter dealt with on page 321 of this book—the final record being printed in all three.

CHAPTER TWO

PHASES IN THE APPLICATION OF SCIENCE TO PRACTICE

INTRODUCTION

THE tendency towards differentiation of function among the different technical professions participating in a common task, illustrated a few pages back in the imaginary example of a hydro-electric work, holds good not only between different divisions of subject matter as there described, but also, cutting across these, between the successive phases in scientific work whereby new knowledge is obtained, recorded, distributed, stored, selected and applied to practical ends.

It is no more possible to draw hard and fast lines between these phases than between the colours of the spectrum, but it will assist clear thinking if an attempt is made to enumerate them in some kind of logical sequence. The column headings in the endpaper chart—quite arbitrarily twelve in number—have, therefore, been chosen to mark the stages in the evolution of scientific ideas from their initial conception in the philosophic mind to their eventual application in the hands of the practical engineer or business man. They will be explained in the present chapter and the actual organisations which concern themselves with these successive phases of technical work—indicated in the chart by the rectangles overlapping the respective columns—will be described in the two following.

The chart is an impressionist sketch, not an accurate map.

The column headings might with equal justification have been arranged quite differently and there is nothing rigid either in their scope or in their sequence. But the treatment of the subject on these lines will have served its purpose if it brings out how, on the road from pure to applied science, each step is made possible by the steps already accomplished and may necessitate (in the terminology of Chapter One) controlled experiment, controlled sampling or controlled guesswork as the circumstances require.

THE CONTROL OF RESEARCH PROJECTS

It may be said figuratively that research in the true sense of the word differs from chance discovery according to the degree of purposive effort that is applied in proceeding across our chart from left to right. There would appear scope for a book or paper dealing with the proper rationale which should underlie the planning and controlling of such effort, as distinct from descriptions which already exist, and will be quoted later here, of the physical layout of laboratories.

Such a book would describe and exemplify the documentary procedure within a research organisation for defining and putting forward the proposal that a particular research project be undertaken; for securing approval of the necessary expenditure; for reporting back the results achieved and listing the laboratory notebooks, reports and bulletins in which these are recorded; and, finally, for securing proper data whereby to balance cost against achievement and promise, which can be used as criteria when seeking to justify and allot priorities to other projects.

An orderly procedure to secure these objects is important, but in many organisations there is room for improvement in the way they are pursued. What is needed is a proper balance between two conflicting desiderata :

(1) There must be sufficient system to ensure that effort is not wasted and that objectives, means, methods and results are rationally related to one another and that the results are made available in convenient form, but—

(2) Procedure must be flexible, so as not to inhibit that individualism which is so important in research work.

Much depends on accurate and logical definition of each project to distinguish it from others so as to enable proper accountancy, and on the layout of the actual proformas used. The following have been suggested which, in the original, are filled in with sample items relating to forestry research projects, but they would serve equally well in other fields :

Headings in Job Outline :	*Headings in Job Closure :*
Title	Title
Objective	Objective
Scope	Achievement
Method of attack	Recommendations
Justification	Data, memoranda and reports
Estimated expenditures	Expenditures
Schedule	

Expenditure on proposed research should preferably be sanctioned not up to a certain limit during the year but up to a limit on each project since the beginning of work on that project, further authority having to be sought when this limit is about to be exceeded. This makes it easier to keep track of a number of projects running concurrently, some of which may be in cold storage for the time being. In a large organisation known to the writer which operates a number of separate research stations in its various factories

[1] E. J. Schreiner : Research organisation and research cost accounts. *Journ. of Forestry* (Washington), Dec. 1940, pp. 909–15. See also *Management Review* (New York), Dec. 1945, summarising a 32-page booklet: The control of industrial research.

Column 4 represents the description of existing materials and of established processes in the clear and precise terms which the preceding phases have made available. In no industry can rule of thumb be superseded by a scientific basis of present problems and of future possible developments until this stage has been gone through; not till then are we at the point when the scientist is able to say, "I have worked out for you from first principles an explanation of the fact that these elements, thus juxtaposed, will operate to produce such-and-such results. Here are formulæ expressing exactly how the reaction takes place as governed by the surrounding conditions", and is met by the organiser or the man of business who says, "Here are problems which call for solution: show me how to use your formulæ to solve them."

A first example may be taken from metallography. Molten lead and tin will mix with one another in any proportions. The former, by itself, solidifies when cooled down to 327° C. and the latter, by itself, when cooled to 232° C., but a mixture or alloy of the two will remain *partly* liquid down to a temperature lower than either of these. The conditions are represented in Fig. 4 in which any point on the curves AB, BC indicates the percentages of lead and tin in a certain alloy and the temperature at which that alloy is capable of existing. The diagram is divided into a number of areas, called *phase fields*, according to the structural constituents present in the alloy under the conditions represented: thus all alloys whose composition and temperature fall in the area above ABC are entirely liquid; those within the area ADB consist of a mixture of solid lead and liquid alloy; those within the area CBE of solid tin mixed with liquid alloy. An alloy containing, for instance, 80 per cent of lead and 20 per cent of tin is represented by

the line *abcd*; at the temperature *a* it is molten, and it remains so down to the temperature *b* which is well below the melting-point of pure lead, but if it is cooled below this solid nuclei of lead begin to form in the liquid, and as the alloy cools from *b* to *c* these grow as " dendrites " similarly to the solidification of a pure metal. Meanwhile the residual liquid, on account of the lead thus crystallising out, becomes richer in tin—its composition at any temperature

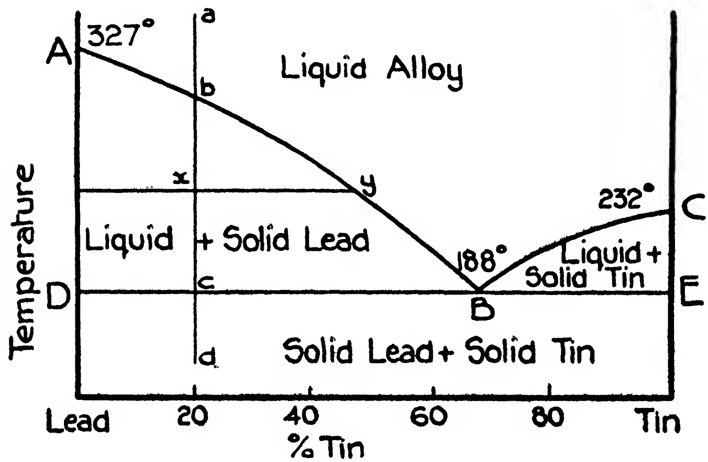

FIG. 4. EQUILIBRIUM DIAGRAM FOR LEAD-TIN ALLOY.

x being found by drawing a horizontal line through *x* to meet the curve AB at *y*. When the temperature falls to *c*, known as the eutectic temperature, the residual liquid has the composition represented by B, and at this point suddenly solidifies, forming a fine-grained mixture of lead and tin crystals surrounded by a matrix called the eutectic. (Alloys initially richer in tin than B follow a similar course in cooling, which may be traced out from the other side of the diagram.)

The illustration is an *equilibrium diagram* or *constitutional diagram*, and in this case of a eutectiferous alloy formed from two elemental metals it is a relatively simple one. Where the metals are more than two in number, or are such that they enter into chemical combinations with one another or form " solid solutions ", the diagrams become more complicated.

In the development of new alloys to meet practical requirements the working out of such diagrams by means of experimental observations and thermodynamical calculations is an essential step, and this will be accompanied by investigations of, for instance, the effects of heat treatment and " cold working " on the properties of the metal.

In chemistry, likewise, the examination and comparison of known materials and of known reactions under varying conditions of temperature, pressure and so forth is a precondition for new developments. For instance, apparatus is set up for maintaining exceptionally high pressures or, on the other hand, exceptionally high vacua, and studies are made of the rates at which reactions take place in these apparatus as compared with ordinary pressure conditions.

The passage from column 4 to column 5 in our endpaper chart is marked by an increase in the number and precision of the various kinds of measurement to which samples of whatever material is in question are subjected. For instance, the selection of materials for engineering construction has become scientific to the extent reflected in the following fairly long list of measurable quantities—each of which is the criterion of excellence in regard to some particular quality required in practical application—which are quoted here from a paper [1] comparing different kinds of steel :

[1] H. J. Gough and W. J. Clenshaw : The testing of engineering materials. *Trans. Inst. Mar. Eng.*, Vol. 47, No. 10, pp. 241–276.

Ultimate tensile stress.
Elongation on 8-in. gauge length, %.
Reduction of area, %.
Tensile limit of proportionality.
Proof stress at 0·005% elongation.
Upper yield stress.
Extension at yield, %.
Young's Modulus (Modulus of Elasticity).
Yield stress of rivet material.
Ultimate tensile stress of rivet material.
Notched bar impact value, ft.-lbs.
Plane bending fatigue limits—
(*a*) on polished specimens.
(*b*) on specimens as rolled.
(*c*) as (*b*), containing circular holes.
Rotating bar fatigue limits—
(*a*) normal specimens.
(*b*) grooved specimens.

Again, the suitability of a material for use as a dielectric covering for electric cables might be judged in terms of the following measurements:

Volume resistivity at 20° C., megohms per c.c.
Surface resistivity at 20° C., megohms per sq. cm.
Power factor.
Dielectric constant.
Tensile strength, with or without 20% filler, lbs. per sq. in.
Elongation at break, %.
Cold resistance.
Water absorption in 11 days at 20° C., % of weight.
Water absorption in 2 days at 70° C., % of weight.
Safe working temperature, ° C.

Soil mechanics may be mentioned as an example of a branch of engineering—important in connection with foundations, retaining walls, and the making of low-cost " sand-clay " roads from local material suitably treated and

stabilised—which has become quantitative and therefore scientific only within the twenty odd years through the development of the following forms of tests :

Mechanical analysis.
Lower liquid limit.
Lower plastic limit.
Plasticity index.
Shrinkage limit.
Shrinkage ratio.
Centrifuge Moisture Equivalent Test.
Field Moisture Equivalent Test.

Unless the reader happens to have studied these particular branches of engineering, he will not, of course, understand the significance of the items in these lists ; nevertheless their enumeration may serve to illustrate the point which will become clearer after the next section has been read, that an essential preliminary to the scientific pursuit of practical objectives is the accumulation of exact data regarding the characteristics of available materials and processes, measured in the same units as are commonly used in thinking about the problems they will be applied to solve.

DESIGN AND SPECIFICATION

We now reach a phase which overlaps columns 5, 6 and 7 in the endpaper chart.

Design, in the engineering sense of the word, is a process of matching requirements against available means and of recording the result of so doing in the form of drawings and written specifications to show how it is to be translated into actual practice.

This process becomes scientific in proportion as both sides of the equation are capable of expression in terms of the same measurable units. Consider, for instance, the design

of a steel girder for a railway bridge. Here the "requirements" side of the equation is made up of (*a*) the conditions due to the site of the proposed bridge, necessitating a clear span of so many feet between supports, and (*b*) the magnitudes of the various loads which it will have to carry, conventionally assumed (in accordance with British Standard Specification No. 153 of 1937) to be made up of—

Dead Load, calculated from the unit weights of the material of the girder itself and of the materials supported by it.

Live Load, to be taken as a succession of axles of prescribed weights moving across the bridge at prescribed spacings to represent two locomotives followed by a train as shown in Fig. 5, the weights of the axles being a suitable multiple (in the case of a main-line railway, 22) of those here marked.

Impact Effect, attributable, in accordance with certain rules, to the presence on the driving wheels of a steam locomotive of unbalanced revolving masses such as the coupling rods, which produce hammer blows on the bridge.

Lurching Effect, due to the reciprocating parts on either side of a steam locomotive.

Wind Pressure on the sides of the bridge.

Centrifugal Force, if the bridge is on a curve.

Temperature Effect, due to expansion and contraction.

Secondary Stresses
Special Stresses } which are peculiarities of certain types of structure.

Erection Stresses, which may arise if any part of the bridge is to be temporarily supported in a way which will cause stresses different from those in the finished structure.

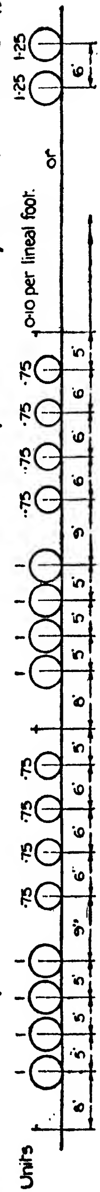

FIG. 5. BRITISH STANDARD UNIT LOADING FOR RAILWAY BRIDGES.

The designer's task is to estimate the combined effect of all these possible loadings and, by ap-

plying the laws of statics, to balance them by the most effective and economical arrangement he can devise of the "available means" as expressed in the kind of data discussed in the preceding section—namely, the strengths and elastic properties of suitable kinds of steel.

Actually in all structural design the estimation of the loads is by far the more difficult and uncertain of the two sides of the equation to evaluate. The loadings assumed for the purpose of calculation are not so much descriptions of actualities as allowances for contingencies which have been assessed so as to err on the side of safety. Thus in the bridge above mentioned the Dead Load is the only portion of the total loading which can be worked out with any approach to certainty and even this is uncertain in a complex or a "hyperstatic" structure where it becomes difficult to determine exactly what share is borne by each member; the assumption of a particular make-up of train to represent the Live Load cannot be otherwise than arbitrary; Impact and Lurching are estimated according to different theories by the engineers in different countries: Wind Pressures are at best a statistical estimate of probability; the Centrifugal Force on a curved bridge depends on the assumed speed of the trains; Temperature Effect depends on the assumed range of temperature to which the bridge is exposed; Secondary Stresses (due to the use of riveted or other rigid joints instead of pin joints) are extremely difficult to calculate.

All this is mentioned in order to emphasise that even in so ostensibly mathematical a process as bridge design the "Definition of practical objectives"—to quote the heading of column 6 in the endpaper chart—is far from being independent of personal judgment.

Yet, throughout engineering and industry, the range of

objectives amenable to precise scientific definition is continually extending. For instance, a subject studied at the Research Station of the London, Midland and Scottish Railway is the improvement of the comfort of seats in passenger trains.[1] The ideal seat should be neither too high nor too low, neither too hard nor too soft, neither too chilly nor too warm. It should not be slippery nor should it drag on the clothing. It must support the small of the back and it must be at the correct angle to support the head as in slumber. The mere qualitative enumeration of these desiderata is in itself a step forward ; but if we can proceed to the further step of measuring the most desirable height, degree of hardness, temperature and coefficient of friction which will suit the majority of passengers, and if we can subject all the available materials to tests of their qualities in these respects, we shall be on a fair way to arriving at the best solution to the problem.

Take another example.[2] What is the best kind of boot or shoe for a waitress to wear, or a nurse, a shopgirl, a policeman, a railway porter, a factory machine-minder and so on? Many large concerns interested in the welfare of their employees would not hesitate to specify a certain shoe as part of their employees' uniform if the best shoe to specify were known. In fine dress shoes flexibility, comfort and elegance are sought and an instrument has been devised which imposes on a shoe the correct kind of deflection and which gives a measure of flexibility so as to provide a means of investigating different ways in which that characteristic can be achieved. Another machine has been designed which puts shoes through the motion of walking and gives soles

[1] Sir Harold Hartley, quoted in *Modern Transport*, 16 Apr. 1938, p. 3.

[2] Report of British Boot, Shoe and Allied Trades Research Association, quoted in *Rept. D.S.I.R.*, 1936–7, p. 128.

the treatment which they receive during wear. This will enable the different kinds of material and the different constructions of shoe to be tested to exhaustion, and so lead to an insight into the best combination to give maximum durability in various circumstances: in other words it will lead to the possibility of *designing* a shoe in the engineering sense.

THE ORGANISATION OF CIVIL ENGINEERING WORK

Our assumption now is that a design has been worked out and embodied in drawings and detailed specifications, showing exactly how some proposed job is to be carried out.

Before explaining the later column headings of the end-paper chart it will be necessary to say something of the organisation adopted and procedure generally followed in turning the paper-borne idea into concrete reality. This organisation and procedure varies, of course, with the nature and size of the work and according to the number of articles to be produced from the one design, and it will be helpful to refer here and in the next section to what may be regarded as the two opposite extremes: that is, firstly to outline how a typical large civil engineering work is executed and then to make some remarks on mass production in a factory. Other forms of production—such as, for instance, electrical installations, shipbuilding, house building, machine construction—must be left for the reader to imagine as occupying positions intermediate between those described.

In the case of a civil engineering project—let us say a bridge, a tunnel, a section of railway, a scheme of road improvements, a reservoir, a large building—the preliminary surveys will normally have been carried out and the design

drawings completed either by engineers belonging to the staff of the public authority or company concerned, or by an independent firm of consulting engineers acting for them and remunerated in accordance with the cost of the work.

The drawings are used in the first place for what is known as *taking off quantities*, which means calculating and listing in systematic form the magnitudes of all the items of work involved—in a large job many hundreds—such as so many cubic yards of different categories of earthwork, so many cubic feet of different varieties of concrete, so many square feet of different thicknesses of brick wall, so many pieces of steel fabricated as detailed in the drawings, and so forth. This operation is now most frequently carried out by specialist firms of *quantity surveyors* to whom the plans are referred by the engineers for the purpose. If so, the resulting *bills of quantities*, as they are called, are printed with the quantities filled in against each item but with cash columns left blank down one side of the sheets, and these are sent with photo-prints of the drawings of the proposed work, and a copy of the specification, to approved firms of contractors who have applied to be allowed to *tender* for the job.

Each of these competing contractors then fills in, against every item in the bill of quantities, both the unit rate (so much per cubic yard, etc.) and the total amount that he is willing to do the work for in accordance with the drawings and specification. He returns the bill to the engineer under seal. On a prearranged date all the tenders are opened and one of the competing tenderers—usually the one whose total is lowest provided he is otherwise considered satisfactory—is awarded the contract. Sometimes, instead of an independent quantity surveyor being employed, each tenderer

is left to take off the quantities from the drawings himself, but as this involves needless duplication of the work and has other disadvantages the above-mentioned procedure is the one tending to be preferred.

The selected contractor then appoints an *agent* or on a smaller job a *clerk of works* to take charge on his behalf of the actual operations and to control the labour on the site. The engineer responsible to the client appoints, on his part, a *resident engineer* to represent him in constantly supervising all the contractor's arrangements ; in checking the setting-out of the works on the ground with theodolite, level and measuring-tape ; in carrying out the tests laid down in the specification for the material delivered to or erected on the site ; in inspecting the work as it proceeds and making sure that it complies in every particular with the drawings and specifications ; and in agreeing with the contractor every month on the measurement of work completed to date and then issuing a certificate enabling the contractor to claim a proportionate share of the contract payment on account.[1]

The above represents what may be called the classical relationship between consulting engineer and contractor wherein the former's functions of specification, design and inspection are entirely separated from the latter's function of execution, and emphasis is laid on the complete independence, financially and otherwise, of these two parties. Though the maintenance of this system has its advocates [2] there are fields of engineering—notably bridges and other structural work—in which it is tending to be superseded by

[1] For a more complete picture of these matters see the paper, followed by discussion, of E. J. Rimmer : The conditions of engineering contracts. *Journ. Inst. C.E.*, Feb. 1939, pp. 3–58 and references mentioned therein.

[2] The Association of Consulting Engineers exists with this object, its members binding themselves to strict observance of the principles involved.

firms organised to perform with their own staff all of these functions from start to finish. Again, in ship construction, some of the larger shipowners have their own staffs of naval architects and engineers who, when a new ship is required, prepare a complete design and specification which is sent to selected shipbuilding firms who are invited to tender for the contract. Other shipowners may employ independent consultants to do this for them, but more often they merely indicate their requirements in outline to a suitable shipbuilding firm and the latter submits its own suggested specifications along with the tender, thus in effect combining the functions of consulting engineer and contractor. Normally such a tender covers everything in the ship but it is itemised under such headings as propelling machinery, refrigerating plant, passenger accommodation, crew accommodation, winches, etc., and the shipowner having considered the itemised tender may prefer when awarding the contract to omit certain items and make independent arrangements for the supply of these.

MASS PRODUCTION AND ITS DEPENDENCE ON GAUGING

Civil engineering typifies a form of organisation suited to certain kinds of work; mass production—the most notable feature in the industrial development of our age—is an alternative suited to other kinds of work which stands in striking contrast with the aforementioned.

The conditions for successful mass production are these:

(1) The market must be such that the product can be sold at a price high enough to cover the cost of production, standing charges, overheads and profit; yet low enough to ensure that the demand will be maintained at a level sufficient to absorb the whole output of a plant of economical size.

(2) This means that the standing charges, overheads and profit *per unit of product* must be brought down to a minimum by spreading their annual total over the maximum possible number of units that can be produced during the year in the same plant.

(3) This in turn means that each item of plant and labour must be specialised to the utmost, every component of the final product down to the smallest bolt or pin being turned out by the hundred thousand in a separate machine designed to perform that function—and that only—with maximum efficiency, and their assembly being merely the last link in a chain of processes.

(4) Hence the fundamental importance of the principle of *interchangeability of parts* and its corollary, precision in the testing of dimensions, which is called *gauging* and is the subject of this section.

Interchangeability of parts involves a compromise between the technical requirement of accuracy and the economic requirement that the cost of ensuring such accuracy must not be excessive. This compromise is found by allowing as large a divergence from perfect accuracy as is possible without rendering the part useless or unsuitable for its purpose. Thus, in the case of a shaft which is to revolve in a bearing, the diameters both of the shaft and of the bearing are permitted to vary over a certain range—some small number of thousandths of an inch—known as the *tolerance*, chosen so that the largest shaft and the smallest hole within these ranges will fit together: i.e., if the smallest shaft happens to be assembled with the largest hole the clearance will not be too great and the fit not too slack, while on the other hand, if the largest shaft happens to be assembled with the smallest hole the tightness will not be so great as to cause overheating. The tools used for testing diameters

in this way are known as *limit gauges* or "go" and "not go" gauges; if, for instance, a shaft is to have a nominal diameter of 1·500 inch two steel rings are provided, one of them being marked "go" and having an internal diameter of 1·501 inch which it must just be possible to slip over the shaft, and the other being marked "not go" and having a diameter of 1·499 inch which it must not be possible to slip over the shaft. The converse kind of "go" and "not go" gauges, in the form of plugs, are used for testing the internal diameters of holes. Other types of limit gauge are in use for shapes other than cylindrical, and an alternative method applicable also to screw threads, gear teeth, etc., is to project a much-enlarged image of the piece under examination on to a screen by optical means.

What is known as *selective assembly* is a departure from strict interchangeability of parts which permits, however, of exceedingly fine fitting without excessive cost of manufacture. Umbrella ribs, for instance, are liable to alter in length by as much as $\frac{3}{16}$ inch in the process of hardening and tempering; to prevent this variation would be impossible or uneconomical, but indiscriminate assembly would result in mis-shapen umbrellas. The ribs, therefore, are gauged for length and sorted into four different classes; the spacing of the holes is also gauged and sorted into another four classes; thus giving eight classes from which assembly can be made by selection.[1]

TESTS

This section deals with the passage from column 6 to column 7 in the endpaper chart.

[1] The last two paragraphs have been adapted mainly from an excellent practical treatise on the subject by H. T. Hildage, T. G. Marple and F. L. Meyenberg: *The New Management.* (London: Macdonald & Evans, 1938.)

When it has been decided what qualities are required in the product the next step is to devise tests which will show how far they have been attained, just as gauging serves to check the accuracy of dimensions. Such tests will be discussed below under the three categories of analytical, simulated performance and actual performance tests. Another classification, cutting across this, is into non-destructive and destructive forms of test, the former being applicable like dimensional gauging to the whole of the product whereas the latter involve taking a sample (the size of which can be worked out from statistics: see pages 18–28) and sacrificing this in the knowledge that it is representative of the rest. The routine application of tests and gauges is called Inspection, which is the heading of column 10 in our chart.

By analytical tests is meant, here, the principle of splitting up a complex quality into its constituent elements and checking each element separately. In regard to road tar, for instance, the general requirement that the material shall be satisfactory in use on the roads is split up, in British Standard Specification No. 76, into a set of separate requirements, and to secure these separate tests are laid down governing (*a*) the specific gravity, in order mainly to serve as a check as against excess of paraffin, (*b*) the water content, in order to improve the adhesive quality and to safeguard the purchaser against having to buy an excess of water in the tar and pay £2–3 a ton for it, (*c*) the distillates, which may have some effect on the consistency of the material when in the road, (*d*) the phenols present, as these are soluble in rain-water and it has been alleged that the drainage carrying them off the road into the streams is harmful to fish life,[1] (*e*) the naphthalene, which is detrimental to the

[1] On this question see page 173.

qualities of viscosity and adhesion, (*f*) the amount of free carbon, which ensures " body " and affords a check on the quality of the crude tar, and (*g*) the viscosity, on which depends the compatibility of the tar with the mineral aggregate and the stability of the resulting mixture.

An example of simulated performance test is the tumbling drum test for wooden packing-cases which has been introduced from America and improved in the Forest Products Research Laboratory, Princes Risborough, as a means of determining constructional weaknesses in boxes such as are used for the transport of canned goods, etc.[1] Sample boxes which it is required to assess in order of merit are placed one at a time inside a hexagonal drum 7 feet in diameter, outwardly resembling a large concrete mixer and rotating at the rate of one revolution per minute. Baffles or projections on the internal face of the drum cause the box to fall repeatedly on to its corners, edges and faces, and the number of drops required to break up the boxes sufficiently for their contents to fall out, together with observations of the test and of the condition of the boxes and of their contents at various stages, can be taken as a measure of the resistance of the boxes to rough handling.

A somewhat similar test to this, in another connection, is the " rattler test " for road paving-bricks as used in America and Holland : the samples, together with hardened cast-iron balls, are placed loose in a rotating polygonal drum, and the loss of weight experienced by them in the

[1] The subject is dealt with in a symposium of three papers : C. J. Chaplin : The Container Testing Laboratory ; J. Latham : The improved tumbling drum test ; C. B. Pettifor : Statistical methods used in determination of specification limits for egg containers ; *Journ. Roy. Soc. Arts.*, 2 Dec. 1938, pp. 78–96. Similar research in the United States is stated to have resulted in reducing the total damage claims paid by the railways to consignors from 120 million dollars in 1920 to under 19 million dollars in 1932.

course of a given number of revolutions affords a measure of their wearing properties.

Some years ago the London Passenger Transport Board, for the purpose of testing and improving the spring fillings then used for omnibus cushions, built a " seating machine " which reproduced mechanically the effect of two passengers alternately loading the seat at either end so as to cause the worst possible distortion of the springs. In 24 hours a fatigue test could thus be given which corresponded to the effects of 12 months' service.

A much simpler example in a different field is the " scratch handicap " sometimes included in Air Ministry specifications for abrasion-resistant aircraft finishes. In laboratory tests a panel coated with the finish is drawn underneath a needle loaded with a known weight, and breakage of the film of finish results in a metal contact being established which is instantly recorded by an electric-lamp signal. In this way the hardness and adhesion of finishes can be determined, tested and checked.

Where the conditions of use of an article in actual service are difficult to represent as a complex of elements amenable to " analytical " testing as here described, and do not lend themselves to a simulated performance test, it is sometimes preferred to rely on statistical examination of the results obtained in actual service by comparing the articles under test with controls the performance of which is already known. This applies, for instance, to motor tyres : when it is desired to test the merits of some slight variation in the normal process of manufacture, tyres made by either method may be placed in service together through the ordinary trade channels, and the reports of performance collected over a suitable period are compared statistically.

Improvements to motor vehicles themselves sometimes

are tested by a rather similar method. Several of the leading manufacturers when about to introduce a new model place the first dozen or so in the hands of selected users with whom they collaborate with a view to obtaining first-hand knowledge of the behaviour of the new product in commercial service. By this means any unforeseen weaknesses are quickly discovered and can be corrected, and "teething troubles" are reduced to a minimum. Collaboration of this kind between manufacturers and users has hitherto been loose and sporadic, but the newly-formed Institute of Road Transport Engineers will seek to co-ordinate it at a common centre, and eventually to disseminate the valuable information so obtained.[1]

Engine and ship trials, and deflection and vibration measurements on bridges and other structures, are non-destructive actual performance tests which serve to confirm the results inferred from the analytical or simulated performance tests which their component elements have undergone before assembly.

Chemical analysis is nothing but a system of tests, qualitative or quantitative as the case may be, designed to show the presence or absence of each element.

Tests are by no means always direct measurements of the qualities it is required to control but may be measurements of quite different qualities with which some correlation has been shown to exist. Portland cement, for instance, is tested for strength in tension although used for making concrete to resist compression. Experiments to arrive at a standard method of comparing the smoothness of wood surfaces showed that optical methods could be employed but that a still better method was to measure the rate at which heat is diffused from the surface under examination.[2] In

[1] Leading article in *The Commercial Motor*, 8 June 1945, p. 329.

[2] *Rept.*, Forest Products Research Laboratory, 1937–8. See also page 107.

studying the synthesis of rubber-like materials it is necessary to make use of some property measurable through the glass walls of the containing vessel which will serve to indicate the extent of the polymerisation (formation of long-chain molecules) that has taken place, and such properties are conveniently found in the refractive index, specific gravity, magnetic susceptibility or electrical qualities of the hydrocarbons in question.[1] To quote another chemical example, the " chain length " or number of molecules connected together in a material of this kind is calculated by taking measurements of the vapour pressure developed at the surface of a sample.

The same indirectness characterises various workshop methods now in use for detecting hidden cracks or flaws, devices to enable boiler inspectors to check the thickness of corroded metal tubes and plates without having to drill a hole and plug it up again after making the measurement, and non-destructive methods for testing the quality of weld seams—this last an important factor in the competition of welding with riveting since the soundness of a rivet can be checked by simply giving it a light tap with a hammer and noticing the " feel ". These requirements are being met by an increasing use of X-rays and of electrical, magnetic and acoustic methods.[2]

Indeed, testing technique offers many examples of how knowledge of one branch of science is necessary for progress in an entirely different branch and, therefore, of the educational importance of a broad acquaintance with fundamentals.

[1] W. J. S. Naunton: *Synthetic Rubber.* (London: Macmillan, 1937.)

[2] Non-Destructive Testing: reprint of symposium of papers arranged by Joint Committee on Materials and their Testing, *Inst. Elect. Engrs.*, 25 Nov. 1938; summaries in *Nature*, 3 Dec. 1938, pp. 1005–6 and *Engineering*, 2 Dec. 1938, pp. 651–2.

STANDARDISATION

This section corresponds to column 8 in the endpaper chart.

Design, specification, the planning of production and the devising of tests all involve skilled and arduous effort by those concerned; hence the special expensiveness of doing anything in engineering or industry that has not been done before.

When what is being done has been accomplished only a limited number of times previously it is preferable that these operations, though costly, should be gone through again or at least reviewed from first principles, for it is improbable that the pioneers who first performed them will have hit upon the best ways of doing so in every detail. But after a number of successful achievements of the same or similar jobs the advantage of repeating the whole of the work of design, specification, production planning and devising of tests *de novo* disappears—or rather, as an economist would put it, " diminishing returns " are obtained for the time and effort so expended—and their cost may, without disadvantage, be saved by copying what has been found to work best in the designs already carried out.

Agreement to this end is known as *standardisation* and is achieved through a process of collative research (see pages 33 and 140) drawing upon the combined experience of an adequate number of suitably qualified people whose opinion as a body is likely to be sounder than that of any one person.

Standardisation which is premature or which does not provide for its own future revision inhibits progress, and formal standardisation of a technique unlikely to pass into repeated and general use is waste of effort; but in other cases

standardisation ("the regularisation or establishment of what is approved as good or valuable") is expedient in that it saves both physical and intellectual effort on the part of all subsequently concerned. Not only so, but where large quantities are involved it is essential for economy in production and marketing. It has been estimated, for instance, that differences in the design of screw threads as between British and American practice added not less than $100,000,000 to the cost of the late war. (See page 164.) In another field, the importance of strict chemical control to ensure standardisation of a product sold in a large market is well illustrated by the following quotation from a paper on the laboratories of J. P. Lyons & Co., Ltd.: "In the pre-war product, taking the price of butter at 120*s.* a hundredweight, a variation in the butterfat content of a quarter of 1 per cent. might have meant an extra profit or loss of £3,000 a year to a manufacturer producing 4,000,000 gallons of ice cream daily."[248·1]

Standards may be internal (within a particular undertaking), national or international. As an example of the first mentioned, one large industrial company which has acquired numerous factories from smaller concerns employs "standards engineers" to draw up lists of the characteristics of all the articles used or consumed for specific purposes in each factory; these lists are analysed and considered by a system of committees on which the central purchasing department of the company as well as the various technical departments are represented. As the result of this activity the numbers of different types and sizes of tools, components, packages, etc., and of specifications for lubricants and chemicals in use have been reduced by 40 to 70 per cent in each category, with obvious economic and other advantages.

It has been suggested that a manufacturing concern should make a point of maintaining systematically a Book of Standards embodying the whole history of its technical attainments in the form of the successive specifications up to those currently in use and serving, therefore, as the repository of its traditions ; the fact that the book is retrospective makes it especially valuable to newcomers on the staff whose inexperience might otherwise impel them to repeat the mistakes of their predecessors.

Standardising organisations in the wider sense are considered in Chapter Four (page 161). The adoption of standards marks an important stage in the passage from a scientific novelty to a commercial product. Commercially, the advantages of setting up a standard of quality or of dimensions and agreeing upon tests whereby conformity to the standards may be recognised accrue both to the producer, who is thus safeguarded against unfair competition, and to the consumer, who is enabled to judge quality and performance in relation to price. A reduction in the number of grades of any given article is reflected in more economical manufacturing and marketing. To give a single example out of hundreds, it was an undoubted gain when the British Standard Specification for Portland cement made it unnecessary for every engineer to enter into details of chemical composition and testing when deciding on his requirements.

PRODUCTION MANAGEMENT

The heading of column 9 in the endpaper chart is intended to describe the work of the executive responsible for organising the actual production of technical goods in accordance with the drawings and specifications he receives. In civil engineering work as outlined on page 52 that executive is

called the contractor's agent, in factory production as outlined on page 55 he is the works manager. Other types of productive organisation exist between these two extremes: house building by traditional methods, for instance, approximates in general character to the first mentioned; mechanical engineering to the latter; shipbuilding comes somewhere between the two; but whatever kind of work is being produced there is some official who, with his staff, performs the functions, and needs to possess the particular kind of technical knowledge, now about to be defined.

The task of the works manager and of his immediate subordinate, the works engineer, is to link the physical with the human. Owing to the accomplishment of the steps represented by columns 1 to 8 in our chart it is known that certain technical processes if conducted in certain ways will yield certain desired economic results: but however automatic, however highly mechanised, these processes may be, the desired results can in fact be realised only through the concerted actions of human beings with the appropriate skills. These actions the works manager and works engineer of a factory, or their equivalents in other kinds of productive organisation, have to control and co-ordinate.

To succeed in so doing the executive concerned must possess, in the first place, technical knowledge of the widest and most practical kind. Whereas the technicians whose functions we have already discussed may be specialists—as long as the "collative" side of their organisation is adequate some of them may even, with advantage, be narrow specialists—the man in actual charge of the job cannot afford to be so. To quote from a review of a relevant book [1]:

[1] W. R. J. Griffiths: *The Works Engineer.* (London: Pitman, 1938.) Reviewed in *Engineering*, 16 Dec. 1938, p. 697.

> In the scope of his interests and variety of his skill the works engineer perhaps comes nearest, of all the species of professional engineer, to the conception of the old-time master millwright. . . . Steam, gas, air, water, electricity and other necessary supplies are his responsibility ; tools, buildings, heating and ventilation, works transport, fire protection and other safety measures are likely to be under his supervision in various degrees.

Secondly, he must understand and be able to plan and give effect to *organisation*, " the art of using the advantages of the division of labour necessary in industry, and of simultaneously avoiding the disadvantages connected with it, as far as possible in the given circumstances " [57·1]. In other words, he must be a leader of men.

Though leadership is an art, not a science, there are many aspects of a manager's work which admit of scientific study and guidance,[1] and on pages 136 to 139 various institutions are named which concern themselves with the elaboration of these. For instance, a technique has been developed whereby a customer's order for goods conforming to a given design and specification is subdivided into internal *works orders* according to the way the plant and labour of the establishment are organised, and the execution of these works orders is planned to the greatest economic advantage on the basis of " work and time studies " or " motion studies ".[2] In making these, account must be taken not only

[1] J. F. Marsden : The literature of scientific management, in *Rept. 5th Conf. ASLIB*, 1928, pp. 40–7, gives references to twenty books on the subject.

[2] E. H. Anderson and G. T. Schwenning : *The Science of Production Organisation* (London : Chapman & Hall, 1938), reviewed in *The Engineer* of 23 Dec. 1938, p. 704, begins with the mention of eighteen elemental units into which manual labour is analysed for purposes of systematic motion study—search, find, select, grasp, position, assemble, use, take apart, inspect, transport loaded, wait (unavoidable delay), wait (avoidable delay), rest, plan and hold.

of actual working time but of losses of time due to the stops agreed upon with the workmen, setting and unsetting of machines, repairs, intermediate time between successive units of work, etc. Failure in this respect has sometimes led to these methods being discredited; moreover, it is of the first importance that a "time study man" should possess the right personality to cope with the fact that "the normal and natural attitude of a worker towards a time study of his work or movements is one of resentment, fear or distrust, or all three combined"; the man with the stop watch must have "nothing of 'the superior person' about him and he must not be so painfully polite and tactful as to create distrust. . . . Any furtive or secret timing will almost certainly be discovered, and inevitably arouse distrust . . ." If, through time studies, the work is rendered more efficient, the worker who has co-operated "is entitled in equity to share in the results . . . and the price of the work must be so fixed as to permit of this . . . any attempt to exploit him in the direction of extracting a greater result for the same wages will assuredly and deservedly fail"[57.1].

In a well-run works this kind of planning in respect of particular jobs proceeds in parallel with more general and continuous efforts to "rationalise" the processes and plant, to prevent accidents, to ensure the most effective and economical lighting and heating and to reduce noise (all of which have an important influence on output), and to improve the methods in use for the selective recruiting of new personnel and the payment and promotion of those already in service. The study of all these matters and much else is rather loosely covered by the term "industrial psychology" for which a special Institute exists (see page 136).

It is the business of the works manager and his staff, then,

to ensure efficient and economical production. The two yardsticks which jointly enable them to measure their success in so doing and make further progress, are *cost accounting* and *inspection*.

Cost accounting is a system designed to arrive at the actual cost of each article produced or of each unit period of service rendered. It is distinct from (though reconcilable with) the ordinary financial accounting which aims only at showing the working results of a business or a department as a whole ; and it is done by a separate staff having a more technical outlook, necessitated by the fact that while the cost of materials and of direct labour expended on a group of articles is easy enough to divide between them arithmetically the equitable allocation of overhead costs presents a difficult problem closely bound up with the technicalities of the work—" overhead costs " being the term for such expenditure as wages paid for lost time, spoilt work, the provision and maintenance of buildings and plant used for more than one purpose, management expenses, and much else. Cost accounting provides the data needed in estimating the costs of future jobs and in seeking to improve the efficiency of production by motion studies and other methods. " Cost accounting assists the management to reduce working costs by pointing out waste and avoidable delay ; to select its output wisely and to vary the quantity of output as circumstances may require ; to choose wisely between alternative methods of operation and production ; to check quotations by comparing estimates of cost made in advance with actual costs as subsequently ascertained. Cost accounting also provides the only reliable means of estimating the value of work in progress ; of determining the extent to which sub-contracting is desirable, and of deciding when

to buy and when to manufacture when each alternative is possible." [1]

Naturally these methods have attained their highest development in reference to the kind of production usually carried on in factories and workshops, but they are extending even to civil engineering contracting.[2]

INSPECTION

Inspection, the heading of column 10 in the endpaper chart, has already been mentioned as one of the functions of the resident engineer acting for "the engineer" responsible to the authority for whom a civil engineering work is being carried out; it involves, in this application of the term, the supervision of routine measures for ensuring that materials and workmanship are up to standard at the time of their incorporation in the work, and also the carrying out of the tests on the completed work prescribed in the specification before it is finally "taken over" from the contractor and the latter's liability discharged. In shipbuilding, the "survey" carried out on behalf of the classification society to serve as a basis for insurance (mentioned again on page 173) bears a somewhat similar connotation. Inspection is also a part of maintenance routine during actual service.

Many kinds of work also are subject to inspection by Government departments such as the Ministry of Transport, the Ministry of Health or the Board of Trade as the case may be, under a procedure which includes the submission of plans

[1] L. R. Dicksee: Cost Accounting, article in *Encyc. Brit.* For a treatise on the more recent developments in costing technique see G. C. Harrison: *Standard Costs—Installation, Operation and Use.* (New York: Ronald Press Co., 1930.)

[2] A. E. Wynn: *Estimating and Cost Keeping for Concrete Structures* (London: Concrete Publications Ltd., 1930) is an example of this. In a section of his paper "Railway bridge construction in Malaya", *The Structural Engineer*, March 1931, pp. 126–9, the present writer has described a simple system of cost analysis applicable to the control of native labour under pioneer conditions.

and calculations before the design is approved. The annual reports of the various inspecting officers are mentioned on page 167 as a valuable source of technical knowledge.

Inspection, as the term is used in factory management, consists in the standardised routine application of the tests and dimensional gaugings which were discussed a few pages back. It may be defined as the systematic comparison of a condition, a quality or an effect as it actually is with what it ought to be : a comparison of the actual with the ideal. The inspection department is, so to speak, the conscience of the concern.[57·1] On the statistical aspect of inspection, known as Quality Control, see page 28.

INVENTIONS, PATENTS AND PLANNING FOR DEVELOPMENT

This section corresponds to column 11 in the endpaper chart.

A technical advance is not of necessity a commercial or social gain. It by no means follows that every invention, every new alternative to existing methods and materials, every new possibility in production, every engineering scheme that can be proved practicable, is one which ought to be carried into effect. For any undertaking whatever in engineering or industry means a diversion of effort and capital resources to it which might be otherwise applied, and affects the profitability of existing business in which capital resources are already tied up and people already employed. The technical merits of a proposal offer no answer in themselves to the much larger question whether its adoption would be likely to result ultimately in a net gain or a net loss, from the point of view either of the firm concerned or of society as a whole.[1] All that can be said

[1] The late Lord Stamp in *The Science of Social Adjustment* (London: Macmillan, 1937) has made the point that civilisation went through a long

with certainty is that it would be one more disturbance added to a jostling interplay of economic factors already so appallingly complex as to defy confident analysis.

Too often new techniques are brought into exploitation without any proper attempt at such analysis or study of their likely repercussions and the result is bad business, unsound investment, wasteful obsolescence of existing plant and the turning adrift of labour specialised in a superseded technique. If these evils are to be avoided there is need not merely to verify the technical claims made for the proposal but to study the probable demand for the new product and the forces which determine this, the existing and possible output of competitive products, the areas or industries in which they are sold, their relative costs and selling prices, the patent position : to build up a complete and balanced picture of the relationship between the economic and technical trends within the field of supply and demand affected. This calls for collative research of a kind much wider in scope than any hitherto mentioned here, requiring familiarity not only with technics in the widest sense but with industrial economics and commercial organisation; research all the more difficult because economics and commerce are not exact sciences, their data are not available in scientific form, and neither official nor other published statistics are classified under the headings most useful for any particular investigation in hand. Hence its material has to

period when the limiting factor to progress was the scientific, but is now passing through a stage when the limiting factors are non-scientific : "the capacities of minds or materials or societies for the rapidity of change, or for the enormous range of change." Technical changes provoke vast social and economic changes over which the individuals whose interests are affected by them for good or ill have no control. The question raised is to whom, and by what means, these social costs might more fairly be made chargeable than to the individuals concerned.

be gathered largely by personal contact with such business men in the trade concerned as are not ruled out as possible competitors, and has to be pieced together largely by the method described on page 29 as "controlled guesswork".

There is no generally accepted name for this kind of research. It may be designated simply as the preparation of data for consideration by a development committee or the board of a company, or it is sometimes called "commercial research", but the latter term is liable to confusion with market analysis (sometimes undertaken by advertising experts) which represents only a part of what is involved. The term "planning" is often employed in the sense intended here but tends to be reserved for investigations conducted as a basis for formulating public policy as distinct from those made by a commercial concern to assess its chances of making a profit.[1] (See also page 169.)

An investigation of this kind may either precede or follow a technical discovery: that is to say, on the one hand a firm may consider it worth while to carry out an "industry review" of some given field of supply and demand with a view to adjusting the objectives of its technical researches in directions likely to encounter useful trade openings, or on the other hand it may wish to assess the possibilities of some invention already made, or of some proposition brought before it. In the first of these cases, therefore, commercial research acts as a kind of induced draught fanning scientific research into flame: a circumstance already touched upon in explaining the endpaper chart when it was suggested that the building-up of scientific knowledge is not only pushed from behind (so to speak) by the "philosophical

[1] The author will welcome suggestions for a book on this which he is now writing under the title *Facts, Files and Action*, which will run parallel to the present work in the fields of social and business planning.

motive" at one end but at the same time drawn forward by the action of the "economic and social motives" at the other. In the second case, the nature of the machinery whereby inventions are offered for commercial exploitation calls for brief mention :

This machinery turns upon the embodiment of an invention in a patent, which is a legal right of monopoly granted by the State enabling the inventor to enjoy (or sell or license to another for whatever price it will fetch) the sole benefit of his invention during a term of years. The first step in applying for a British patent is to deposit at the Patent Office a Provisional Specification briefly describing the invention in due form, and to pay a fee of £1. Acceptance of this affords protection during a period up to 12 months (extendable to 13 months) while details of the invention are being completed, and serves to establish priority over other inventors. The patent may later be completed by payment of further fees and the submission (which depends on various conditions being fulfilled) [1] of a Complete Specification, illustrated by drawings, in which the inventor "particularly describes and ascertains the nature of the said invention and in what manner the same is to be performed". A corresponding procedure is necessary to obtain patent protection in foreign countries, and the total cost including the latter may amount to some hundreds of pounds. In practice the procedure is usually carried out on the inventor's behalf, and the specifications drafted for him with the necessary technico-legal precision, by professional

[1] *Instructions to Applicants for Patents* are obtainable free of charge from the Patent Office. The Institute of Patentees, Inc., provides advice and assistance on both the patenting and the marketing of inventions. An official Committee on the Patents and Designs Act is now reviewing the whole subject and its second interim report was discussed in *Nature*, 6 July 1946, under the title "Patent law reform in Great Britain".

patent agents. The Complete Specification, on acceptance, is printed by the Patent Office and made available for public consultation and purchase (see page 224). These documents form an important branch of technical literature by the scanning of which it is possible to become aware of new inventions long before they percolate to the periodical press (see page 202). Progressive firms sometimes maintain a special staff to keep patents continuously under review and ensure awareness of whatever may affect their interests.

It is on the basis of the Patent Specification that the inventor's rights in his invention may be offered to a manufacturing firm, and reputable firms make it a rule not to consider outside offers of unpatented inventions lest they be placed in a false position in the event of their own staffs being already engaged (as may easily happen) in exploring similar lines of thought. But generally speaking, and strokes of genius apart, the day of the lone inventor may be said to have passed and progress more often results from the co-ordinated team work of organised research departments. It is a little difficult, naturally enough, for a private inventor to understand that in the eyes of a manufacturer (or equally in those of a Government department) a bare idea is of very little value. In point of fact nothing is easier, for a person with an inventive turn of mind, than to invent. Ability to do so is by no means rare; indeed, the daily work of designers and other engineers consists largely in making inventions to order as occasion requires. What is far more difficult, lengthy and hazardous is so to plan and control the application of economic resources as to evoke those inventions, and carry those schemes into effect, which will yield a maximum return. Nine-tenths of the merit and labour of a successful invention lies not in its initiation but

in its commercialisation; in the dovetailing of the new idea into the existing technological *and economic* environment.

The institution of private property in knowledge, as embodied in patents, is a peculiarity of industrial science not shared, for instance, by medical science. In the long run, is society as well served by the competitive commercial system based on this fact as it might be if enterprise were to be planned directly in the public interest? Would the improvement and application of technology be favoured by what Dr. Julian Huxley has defined as " the replacement of the present socially irresponsible financial control by socially responsible bodies " ?

The negative answer to the first and the affirmative to the second of these questions have been argued by Professor Bernal,[1] who holds that private profitability coincides only by chance with communal advantage; that its pursuit causes unhealthy speculation; that the attendant secrecy retards the growth and spread of knowledge; that money which should be spent on research is wasted on litigation and advertising.

The arguments on the other side are (in the philosophical sense of the word) pragmatic. The pursuit, by competitors, of commercial advantage does provide incentives —powerful incentives—to technical research and the benefit of this does ultimately reach the consumer. As a case in point, competition between gas and electricity for lighting, heating and cooking in the home has stimulated immense improvements in both. Secondly, it is much easier to assess " profitability " from the point of view of a finite organisation like a particular company, than from that of

[1] J. D. Bernal: *The Social Function of Science.* (London: Routledge, 1939.) For an interesting criticism of Professor Bernal's criticisms see *The Economist,* 11 Feb. 1939, pp. 278–9.

the community as a whole. In proportion as public control replaces commercial competition, those who have to decide policy will be deprived of the convenient yardstick which the competitive principle now places at their disposal, and the technique of planning will have to be elaborated accordingly to find a substitute.

This is not to say that the thing cannot be done—some of the efforts that are being made to establish planning as a technique with criteria of its own are mentioned on page 170—but that its attainment presents a difficult task likely to become more and more pressing as industries and services become integrated into larger units, whether state-controlled or otherwise. An example in which decision by competition was ruled out by the nature of the case, so that an alternative principle had perforce to be found, occurred in the pioneer development of television when the choice had to be made between the Baird and the Marconi-E.M.I. systems. The expedient actually adopted was to transmit all television programmes on both systems during an experimental period of six months and then to refer the question to a committee (which decided in favour of the latter).[1] Is it possible to ensure that whenever such a case arises, in any field of applied science, it can be referred to a committee so independent, so wise, so well informed and so prescient that it will be decided with the remorseless infallibility—*in the long run*—which would result from the free interplay of the commercial merits of the two sides of the question if they could be left to themselves? That, in its technical aspects, is the problem of planning.

[1] Sir Noel Ashridge: The development of television. Hawksley Lecture at Inst. Mech. Engrs., abstract in *The Engineer*, 11 Nov. 1938, pp. 526–9.

THE KNOWLEDGE-VALUE OF ACHIEVED RESULTS

Accretions to the world's stocks of technical knowledge, which all who have the key may subsequently use, arise not only in response to deliberate quests as indicated in discussing columns 1 to 8 of our chart, and not only as by-products in the manufacture and marketing of technical goods as suggested in discussing columns 9 to 11, but also as an aspect of the technical goods themselves.

For instance, one way in which commerce stimulates the growth of science is through the " technical sales service " which some producing firms (and trade development associations supported by such firms) maintain. Such a service is staffed by experienced technicians whose eyes are turned not inward on to matters of production but outward on to questions of the use made by customers of the firm's products ; men whose job it is continually to study customers' technical problems and to assess the possibilities of development from the customers' standpoint. They are not salesmen in the ordinary sense, but their ever-widening knowledge enables them to give valuable advice—not necessarily confined to direct promotion of their own employer's interests—and in exchange for this they gain unrivalled opportunities of drawing attention to problems that might with advantage be made the subject of research.

Economically speaking, a bridge, a building, a ship, a sewerage system for a town or a year's output from a factory is an end in itself. It is in fact created for that reason and for no other. But incidentally to this economic purpose it is also a new piece of knowledge : new in the sense that the minds of those who have participated in its achievement —each contributing his large or small share as outlined in

this chapter—have been enriched by a new experience; have realised, and by realising evaluated, yet one more of the infinite number of possible combinations of physical with economic relationships. They will be that much better equipped for any future undertaking of a similar kind.

This intrinsic value of knowledge acquired through practice is independent of whether or not any new scientific law has been established in the course of the research or any novel device hit upon in the design and specification: what is new and valuable is the particular *conjunction* of items that have gone to make the whole—just as every one of the words in this book has been used before, but it is a new book because they have never before been arranged in this order.

To anticipate here what belongs to Chapter Four (see page 141), one of the most important functions of the engineering institutions and similar professional societies is that of encouraging the compilation, and providing for the discussion and publication, of papers which form permanent and reasoned records of just such conjunctions of items as are mentioned above: the reasons why the work was undertaken, its economic background, the alternatives considered, the availability of precedents or the necessity for *ad hoc* research to take their place, the results of such research, the principles followed in defining the objectives, the methods adopted in the design of the work, the features of the specifications, the contractual arrangements and their outcome, the manner of execution, the difficulties encountered and how they were overcome, the tests carried out and their comparison with the anticipated values, the total and unit costs of the various parts of the completed work and their comparison with the estimates made beforehand—all those lessons which can be fully learned only in the least public of all schools, practical experience, and which only in this

way can be rendered transmissible to others and incorporated in science.

In our endpaper chart "Learned societies and professional institutions" are represented by a long rectangle at the base, into and out of which are arrows to suggest how these institutions draw knowledge from the publications and records of every phase of scientific activity, and repay it, enriched by their own collative activity, in the form of the publications they themselves add to the stream. For the reasons explained in the preceding paragraph there is no more precious part of this rectangle—figuratively speaking—than its right-hand extension underneath the heading "Applications of products" in column 12.

CHAPTER THREE

BRITISH EXPERIMENTAL ORGANISATIONS

INTRODUCTION

THE stages of knowledge-building differentiated and described in the preceding chapter tend to be localised in different kinds of establishments wherein the personnel, equipment, methods and finance are suitably specialised.

Here again there is nothing hard and fast about the picture that can be drawn, but it will promote clarity to visualise the various types of organisation as rectangles in the endpaper chart overlapping the respective columns of which the headings have already been discussed. The tapered extensions of these rectangles are intended to suggest that, although each type of organisation relies for its raw material *mainly* on the knowledge produced by those on its left, none of them strictly limits its functions to what is implied by its position in the diagram.

The organisations mentioned in the present chapter are those which possess their own laboratories and are able, therefore, not only to collate pre-existing items of knowledge as are those in the next chapter, but also to manufacture their own supplies of primary data by experiments, tests and analyses as occasion requires.

The opportunity will be taken, in passing, to name their respective periodical publications.

EXPENDITURE AND NATIONAL POLICY IN RESEARCH

The total expenditure on research is difficult to estimate and only very tentative figures have been put forward.

Professor Bernal,[76·1] quoting from an investigation by the Association of Scientific Workers some years before the war, gives the following round totals which are of interest chiefly as indicating the proportions of activity in the different fields :

		£ per annum
Universities, learned societies and independent foundations		1,500,000
Government :	Defence services	2,000,000
	Industrial research	600,000
	Medical research	150,000
	Agricultural research	200,000
Industrial :	Contributions to Research Associations	200,000
	Independent	2,000,000
		£6,650,000

Dr. Glanville, the Director of Building and Road Research, in his paper on civil engineering research [1] has attempted to juxtapose such figures as are available against the total annual expenditure on engineering works in the respective fields taken from the *Census of Production*, 1935 (or, in the case of Roads, from the *Road Fund Report*, 1936–7):

	Research.	*Works.*
Roads	£56,000	£55,000,000
Railways	20–30,000	20,000,000
Maritime and Waterways	No figs.	6,000,000
Water supply	,, ,,	7,000,000
Sewerage and Sewage disposal	,, ,,	7,000,000
Structures and buildings	70,000	190,000,000

It would be a welcome development if the Income Tax authorities, on the basis of the concessions in tax now to be allowed on account of research expenditure, were enabled to publish better figures in respect of research by the

[1] W. H. Glanville: Civil engineering research and its future. *Jour. Inst. C.E.*, May 1945, pp. 211–67.

independent industrial firms which account for the great bulk of activity in this field.

In a popular lecture [1] before the Indian Science Congress, the eminent Secretary of The Royal Society has expounded the principles which should underlie a sound national organisation of research and, in particular, the proper relations between scientific bodies and the state. As will be shown in the following pages, many such bodies now receive substantial support from public funds: but it is in accordance with a healthy British instinct that "nearly always when this is done a buffer of some kind is interposed to prevent Government support from becoming Government control". As instances of such "buffers" he mentions the University Grants Committee composed of independent scholars and scientists (see [87·1]) in the case of the universities and The Royal Society in the case of the National Physical Laboratory (see page 94).

Two important larger works have appeared whilst the present book is in proof. In the first of these,[2] "intended for the intelligent layman", two distinguished former officials of the D.S.I.R. review in 30 short chapters the principal industries and public services of the country from a historico-scientific point of view showing their dependence on the research organisations which are described in the concluding third of the book. The other publication,[3] which is to be an annual one, is a compendium of short articles dealing firstly with 28 subjects on which research is now proceeding and then with the organisations of all kinds

[1] A. V. Hill: The scientific organisation, official and unofficial, in the United Kingdom. *Science and Culture* (Calcutta), Feb. 1944, pp. 312–21.

[2] Sir H. Frank Heath and A. L. Hetherington: *Industrial Research and Development in the United Kingdom—a Survey.* (London: Faber, 1946.)

[3] E. N. da Andrade (advisory editor): *Industrial Research.* (London: Todd Publishing Co. Ltd., 1946.)

concerned, followed by detailed directories to these, a Who's Who of individuals, and other useful matter.

RESEARCH IN UNIVERSITIES

The first of the rectangles in the chart, labelled " Unattached individuals ", calls for no comment except on the one hand that the spirit moveth where it listeth and it is open to anyone to initiate ideas, and on the other hand that nowadays the amount of experimental (as distinct from collative) research performed by private persons working in their own laboratories at their own expense is insignificant compared with what is done in organised establishments.

Apart from this the freest kind of scientific research, the least restrained by considerations of immediate commercial applicability and therefore the most congenial to the philosophic outlook which regards knowledge as an end in itself, is carried on in universities; partly by the professors and other staff in the portion of their time not taken up with teaching, partly by research fellows who do nothing else, and in greatest volume (though not in greatest value) by post-graduate students working for a higher degree such as M.Sc., Ph.D. or D.Sc.[1] This involves two or three years of original research work under the general supervision of a professor who is often able to help the candidate by suggesting for him a suitable subject and line of attack. Attendance is not necessarily full-time and many students, especially in London, obtain their doctorates by hard work in such leisure as their professional employment affords.

[1] The Ph.D. degree does not imply studies in philosophical subjects but is the title given to the lower grade of doctorate in any faculty. The D.Sc. is frequently awarded for published work done outside the university, but the possession of a bachelor's degree is a pre-requisite to working for any of these higher degrees.

In the applied physical sciences the research is usually, though not always, of a kind involving experimental investigations by the candidate himself. Whatever its nature it culminates in the writing of a *thesis* which, in order to satisfy the conditions for the degree, must constitute a new and original contribution to knowledge. Theses vary in length from a few thousand words to considerable books. Their literary form has to be suitable for publication, and either type-written or printed copies are deposited in the library of the University concerned where they may be consulted by readers, but publication is not a condition for the degree and only a small proportion of British university theses are in fact published either as books or (whether in full or abridged) in the columns of technical journals.

The freedom of a university researcher to follow, within limits, any line he chooses, and the natural tendency to concentrate mainly on the more fundamental kinds of knowledge-building indicated by the column headings on the left-hand side of our endpaper chart, may best be illustrated by the following titles of London Ph.D. theses during the past few years, taken quite at random from the index in the library of that university (see also page 200) :

Engineering

Laminar and turbulent flow in parallel and converging pipes with smooth and rough walls.

Some applications of photo-elasticity to engineering problems.

An investigation into the problem of the automatic control of temperature in engineering plant.

Engineering, Chemical

A study of the mechanism of filtration.

The transfer of heat from steam condensing on a vertical surface.

A study of lubricating oils with reference to their properties, chemical stability and "oiliness".

Engineering, Civil and Mechanical

An investigation of the characteristics of various substances with a view to their use as working fluids in heat engines.

A theoretical and experimental study of the stress distribution in an electrically welded steel Vierendeel truss.

The gyroscopic stabilisation of land vehicles.

Engineering, Electrical

An investigation of transient phenomena and the behaviour of insulating materials subject to high frequency electric fields.

Interference between power and communication circuits.

Researches on the earth resistivity method of geophysical surveying.

Chemistry

Studies of the oxidation of vulcanised rubber.

Physico-chemical studies of complex acids.

An investigation into the kinetics of solid reactions.

As compared with some other countries, the amount of research done in British universities is small. One reason for this is the relatively low proportions of university students to total population in England and Wales:

England	1 in 1,013	Sweden	1 in 543
Wales	1 " 941	France	1 " 480
Italy	1 " 808	Scotland	1 " 473
Germany	1 " 604	Switzerland	1 " 387
Holland	1 " 579	United States	1 " 125

These figures, which are for 1938, are quoted at second hand [1] and I do not know their original source. They do not take account of variations in the quality of education and research in the different countries, nor of possible variations in the proportion of undergraduate to post-

[1] T. F. E. Rhead: University and industry—alliance for greatness. (Presidential address to Midland Association of Gas Engineers and Managers.) *Gas Journal*, 3 May 1944, pp. 565–9.

graduate students engaged in research; but they are nevertheless interesting.

Apart from these students' theses the research work carried on by the permanent staff of universities, founded on greater experience and correspondingly more authoritative, is continually being published in papers before technical societies and through the other usual channels.

There are, in Great Britain,[1] 16 universities, three independent university colleges, and two other technical colleges of university standing whose total incomes of £6,410,431 in 1936–7 was derived:

14·8%	from endowments
2·4%	from donations and subscriptions
8·5%	from grants by local authorities
36·1%	from Parliamentary grants through the Treasury, Board of Education, and other Government departments, totalling £2,311,978.
30·6%	from fees paid in respect of students
7·6%	from local authorities and other bodies, industrial firms, etc., for services rendered in the way of research, testing, analyses, etc.
100·0%	

Most of the expenditure met out of this income arises from the purely educational functions of the universities which are considered in Chapter Ten of this book, but it also helps to support the research work under consideration here. To determine what share of the total is chargeable to research would be a difficult problem in cost accounting, which does not appear to have been attempted, and the reader must be content to form his own impressions from the proportions of the total numbers of students returned as having been

[1] The statistics which follow are extracted from the very full annual *Returns of the University Grants Committee*. Every fourth year these returns are appended to a *Report* containing discussion of problems relating to students, buildings, staff, libraries and reading, etc. Other grants are made to certain individuals by the D.S.I.R. (see page 97).

engaged in "research and other advanced work" in 1936–7 (see following table).

	Full time.	Part time.
Aeronautics	12	1
Architecture	9	20
Building	1	—
Dyeing	3	2
Engineering—general	23	1
Engineering—chemical	46	3
Engineering—civil	37	6
Engineering—electrical	62	9
Engineering—mechanical	31	9
Fuel technology	12	10
Glass technology	2	—
Leather manufacture	1	1
Metallurgy	44	11
Mining	2	4
Naval architecture	5	2
Oil technology	6	1
Technical optics	5	13
Textiles	24	4
Total advanced students in technological subjects	325	97
Total advanced students in other subjects	2,599	1,867
Total advanced students in all subjects	2,924	1,964
Total undergraduate students in technological subjects	4,167	10,839
Total undergraduate students in other subjects	42,598	
Total, all students in all subjects[1]	49,689	12,803

[1] *The Economist*, on 9 and 16 Feb. 1946, published two articles entitled "Expanding Universities", proposing that by 1960 the capacity of the existing universities should be increased to 90,000 students and that new foundations should be opened to accommodate a further 10,000. According to *Nature*, 2 March 1946, Parliament was to be asked to vote £9,450,000 in grants to the universities for 1946–7 (including £2,250,000 in capital grants). *Nature*, 13 Apr. 1946, pp. 457–60, has a leading article reviewing *The Economist's* proposals.

In future, technological research in universities should receive a stimulus from the increasing number of research fellowships which are being founded by such organisations as Cortaulds, Ltd., the London Midland and Scottish Railway and Imperial Chemical Industries Limited, which wisely are designed to support fundamental as well as applied research. The L.M.S.R.'s scheme provides also for the seconding of experienced members of its own research staffs to serve in universities where they will not only conduct researches but participate in the teaching, and for inviting members of the university staffs to spend some months at Derby, thereby improving the liaison between the academic and the practical worlds. But in this matter we have a long way to go, in Britain, to overtake the United States as described at (*d*) on page 192.

The particular lines of research which tend to be preferred in each university laboratory depend partly on the availability of special equipment, partly on the reputation of individual professors and the extent that they attract a following. In experimental research in engineering it may be the former of the considerations that predominates, in chemistry the latter, in physics the one or the other according as expensive apparatus can be simplified and generalised; thus research involving extreme low temperatures which used to be concentrated at Leiden in Holland, and spectrographic analysis which was a speciality of Liverpool, are no longer confined to these centres since the apparatus has become generalised. Detailed indications of the lines of research pursued in the different universities are difficult to obtain. As regards engineering, short reports based on visits to the laboratories in question, summarising the work going on, used to appear in the *Journal of the Institution of Civil Engineers*. The following are references to such reports up to the

outbreak of war, giving the dates and page numbers in that *Journal*, the subdivision of the respective laboratories into departments, and indications of the more salient researches there described :

Sheffield University (*March 1936*, pp. 369–73).
Structural : connections.
Ferrous Metals : corrosion under repeated stresses.
Reinforced Concrete : strain distribution.
Hydraulics : flow in pipes.

Bristol University (*April 1936*, pp. 598–600).
Civil : for Steel Structures Committee.
Mechanical : failure of shafts under static torsion.
Electrical : whirling of shafts, clocks.

Birmingham University (*June 1936*, pp. 347–50).
Civil : steel beams encased in concrete.
Mechanical : internal-combustion engines, heat transfer.
Electrical : magnetisation, illumination, wear of trolley wires.
Oil Engineering : stability of drilling strings for deep bores, lubrication.
Metallurgy : alloys of tin, cadmium and antimony.
Mining : utilisation of coal, mine-rescue apparatus.

City and Guilds Engineering College (a section of the Imperial College of Science and Technology, South Kensington) (*November 1936*, pp. 148–53).
Structures : stress analysis, influence lines.
Hydraulics [1] : weirs and spillways, silt transport, sand transport by wind, flow in open channels.
Highways : stabilisation of earth roads, slipperiness of surfaces.
Mechanical : heat transfer.
Electrical : high-frequency work.

Kings College, London (*December 1936*, pp. 312–14).
Civil and Mechanical : stresses in structural frameworks,

[1] The Hydraulics Laboratory at this college is the best equipped in the country. For particulars of such laboratories elsewhere, see [17.2].

creep of concrete, injection in heavy oil engines, engine noise.

Electrical : motors and generators, dielectrics.

Battersea Polytechnic (*January 1937*, pp. 490–2).

Civil and Mechanical : vibrated and reinforced concrete, hydraulics, Diesel engines.

Electrical : magnetic properties of alloys, thyratrons.

Woolwich Polytechnic (*February 1937*, pp. 229–30).

Civil and Mechanical : coefficient of expansion of concrete, wire ropes.

Electrical : properties of electrolytes, wireless communication, television.

Victoria University, Manchester (*March 1937*, pp. 450–1).

Hydraulics : hydrodynamics using models.

Structural : stresses in grain bins.

Mechanical : heat transfer in internal-combustion engines.

Electrotechnics : high-frequency work.

Queen Mary College, London (*June 1937*, pp. 281–3).

Civil : foundation pressures.

Mechanical : Diesel engines.

Electrical : resistance-temperature coefficients, high-frequency work.

Kings College, University of Durham, Newcastle-on-Tyne (*October 1937*, pp. 585–7).

Civil : photoelastic stress measurements.

Mechanical : torsional vibration in crankshafts, piston rings, internal-combustion engines.

Marine : propellers.

Electrical : miners' lamps, variation of electrical resistance with thickness of ships and boiler plates, breakdown resistance of gases.

Mining : geophysics.

University College, London (*November 1937*, pp. 153–5).

Civil and Municipal : earth pressures, concrete mixing, water treatment.

Mechanical: flame propagation.
Electrical: magnetic properties of alloys, noise of transformers, electro-communications.
Chemical: distillation and absorption, shellac.

Oxford University (*December 1937*, pp. 310–12).
Civil and Mechanical: impact testing, viscous flow, standing waves, stress calculation in frameworks.
Electrical: dielectrics, wireless.

Leeds University (*January 1938*, pp. 468–73).
Civil: elastic and plastic strains in reinforced concrete and other work.
Mechanical: internal-combustion engines.
Electrical: transmission lines, thyratrons.
Fuel and Metallurgy: gas-making, corrosion of metals in flue gases.
Mining: shot-firing.

Northampton Polytechnic, London (*February 1938*, pp. 98–9).
Civil: stresses in riveted joints, embrittlement of steels.
Mechanical: methods of engine trials, motor-cycle engines.
Electrical: excitation, dielectrics.

University College, Southampton (*March 1938*, p. 312).
Exhaust noise, wind tunnel experiments.

Royal Naval College, Greenwich (*June 1938*, pp. 350–2).
Welding, fatigue of metals, plastic yield and cracking, light alloys for pistons, wind tunnel work, lubrication, other researches of more purely naval interest.

Glasgow University (*October 1938*, pp. 579–80).
Roads and Railways: curves.
Hydraulics: jump.
Materials and Structures: plasticity, fatigue, welding.
Heat Engines: oil engines, gas turbines.
Aeronautics: wind tunnel and other work.

Cambridge University (*April 1939*, pp. 613–16).
Engineering: Oscillation of wheels on a railway track, secondary stresses in framed structures; effect of speed of testing on properties of materials; internal-combustion engines, heat transfer, sound reproduction.
Aeronautics: air flow and turbulence, aeroplane controls.

The Royal Naval College, mentioned above, is an institution of high standing maintained by the Admiralty to train candidates for the Royal Corps of Naval Constructors, among whom private students of naval architecture and marine engineering are also admitted. Apart from the universities [1] themselves, and colleges of equivalent grade such as this, advanced work is done in many miscellaneous educational establishments.[2]

A booklet issued by the Royal Society at its Empire Scientific Conference in June 1946 entitled *Notes on Current Scientific Researches in the United Kingdom* contains a list, similar to the above, of subjects on which work is proceeding both in universities (87 pages) and in other institutions (41 pages) tabulated against the names of the professors or directors in charge and the main subjects—not limited to engineering and industry but including also medicine, agriculture, etc.—to which the specific researches belong.

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

The expenditure of British Government funds on research began in 1850 with the initiation of a payment of £1,000 per annum—increased in 1877 to £4,000 per annum—to the Royal Society for the promotion of scientific enquiries. Expenditure through various channels gradually increased

[1] *The Yearbook of the Universities of the Empire* (London: Universities' Bureau), giving the names of the professors and lecturers and of their respective departments, may afford clues to the nature of the research carried on. It has appendices on centres of scientific research and information, post-graduate scholarships, etc. For references to similar information outside the British Empire, see page 179.

[2] *A List of Official Chemical Appointments* (London: Institute of Chemistry, 9th edn., 1937) includes similar particulars of *all* grades of colleges and schools among the other institutions concerned with chemistry and allied sciences.

until by the turn of the century it amounted to about £45,000 a year, but original research continued to be mainly the task of the individual scientists at their own expense, industry giving little or no support, and the National Physical Laboratory founded in 1899 under the control of the Royal Society (which still directs its scientific policy) represented almost the only notable advance until the repercussions of the Great War brought about a change in the public attitude.

As a result of this a committee which had originally been set up to consider war inventions was reconstituted in 1915 as a Committee of the Privy Council for Scientific and Industrial Research to direct the application of any sums of money—sums which in 1938 came to over £637,000—that might be provided by Parliament for the expenditure in the field indicated by its title. In 1916 the Department of Scientific and Industrial Research was created in its present form as a government department having its own parliamentary vote to serve under the direction of that committee (which consists, since 1928, of Ministers only), taking over the administration of the National Physical Laboratory and of the other research stations, subsequently formed, which are about to be named.[1]

The Department is actually administered by an advisory committee responsible to the above-named committee and consisting of fourteen eminent scientists aided by assessors appointed by twenty-two Government departments. The Department operates through the following Research Boards with their respective experimental establishments and associated or subordinate committees as named below. The

[1] The names, academic qualifications and grading of the scientific staffs may be found in the annual reports of the respective establishments. Vacancies are advertised when they occur and selection is by competitive interview, but there is no special examination. Women are admissible.

figures in brackets represent the total gross expenditure minus the receipts from fees paid by industry and by other Government departments for special services rendered, contributions to co-operative research, etc., for the year 1937–8 which, owing to the war, is the latest year for which a *Report of the D.S.I.R.* has been published.

NATIONAL PHYSICAL LABORATORY, Teddington.
(£252,209 – £141,302.)
Executive Committee.
Research Committee.
Joint Committee (with Building Research Board) on Architectural Acoustics.
Atmospheric Pollution Research Committee.
Gas Cylinders and Containers Committee.
Illumination Research Committee.
Lubrication Research Committee.
Committee on the Application of X-Ray Methods to Industrial Research.
Grain Infestation Research Committee.
Advisory Committee on Radium Beam Therapy Research (jointly with Medical Research Council).

CHEMISTRY RESEARCH BOARD, directing Chemical Research Laboratory, Teddington.
(£27,326 – £3,986.)
Corrosion of Metals Research Committee.
Road Tar Research Committee.

WATER POLLUTION RESEARCH BOARD.
(£9,134 – £3,713.)
River Mersey Committee.
River Tees Survey Committee.

FOOD INVESTIGATION BOARD, directing Low Temperature Station for Research in Biochemistry and Biophysics, Cambridge, and Ditton Laboratories, East Malling, Kent.
(£54,709 – £9,302.)
Committee of Management of Low Temperature Station.
Engineering Committee.

FOREST PRODUCTS RESEARCH BOARD, directing Forest Products Research Laboratory, Princes Risborough.

(£41,854 – £3,013.)

Wood Preservation Committee.

BUILDING RESEARCH BOARD, directing Building Research Station, Garston, near Watford.

(£97,382 – £56,756 including Road Research).

Physico-Chemical Committee.

Fire Resistance Research Committee.

Joint Committee with Fire Offices' Committee on Fire Grading of Buildings.

Standing Committee on Heating and Ventilation.

Joint Committee with Medical Research Council on Research in Heating and Ventilation.

Committee on Testing Work for the Building Industry.

Wind Pressure Research Committee.

Standing Advisory Committee on Testing Work for the Building Industry.

ROAD RESEARCH BOARD, directing Road Research Laboratory, Harmondsworth, West Drayton.

(Now has its own budget.)

FUEL RESEARCH BOARD, directing Fuel Research Station, Greenwich.

(£103,240 – £8,458.)

Coke Ovens Committee.

Committee on Complete Gasification of Coal (jointly with Institution of Gas Engineers).

Powdered Fuel Engine Committee.

13 Local Committees of the Physical and Chemical Survey of the National Coal Resources.

GEOLOGICAL SURVEY BOARD, directing Geological Survey and Museum, South Kensington.

(£73,482 – £2,010.)

METALLURGY RESEARCH BOARD.

Committee on the Behaviour of Alloys at High Temperatures.

RADIO RESEARCH BOARD.

OTHER EXPENDITURE AND RECEIPTS:

£29,659 — £1,514 for Headquarters Administration of D.S.I.R.
£148,282 — £750 to Research Associations (see page 111).
£26,391 — £64 to students, etc.

GRAND TOTALS OF EXPENDITURE MINUS RECEIPTS:

£872,127 — £234,927 = £637,200 net in 1937–8.

These pre-war totals compare with estimates of:

£1,817,217 — £411,946 = £1,405,271 net in 1945–6.
£2,711,567 — £320,633 = £2,390,934 net in 1946–7.

The item "students, etc." ending the list relates to yet another responsibility of the Department, the payment of allowances as follows to research students in universities, the figures quoted being those for the academic year 1937–8:

	Maintenance Allowances for "Students in training".	*"Senior Research Awards."*	*"Grants for Special Investigation."*
		Normal duration:	
	1 year.	*3 years.*	*1, 2 or 3 years.*
Chemistry	62	6	21
Physics	29	2	19
Mathematics and Astronomy	2	—	—
Biology	28	2	7
Geology and Mineralogy	3	—	1
Metallurgy	7	—	3
Engineering	8	—	5
Total	139	10	56

These awards which the Scientific Grants Committee of the D.S.I.R. has power to make to individuals when the

"timeliness and promise" of a proposal so justifies are quite distinct from the support afforded to universities by the University Grants Committee.[87·1] Recent examples of the D.S.I.R. grants have been for investigations carried out at Cambridge in reference to radio propagation, intense magnetic fields and large-scale plant for the liquefaction of hydrogen. As compared with £26,391 in 1937–8 their estimated total is £6,500 for 1945–6 and £67,000 for 1946–7.

The annual *Report* of the Department of Scientific and Industrial Research, which last appeared in 1938 and is the source of most of the above data, was a book of nearly 200 pages which included a summary of the work of each of the Boards, with bibliographical references; also the membership of the Boards and Committees. The report each year made interesting and informative reading as did the reviews of it which used to appear in the leading technical journals.[1] For an account of the activities of the Department including the war period reference may be made to a recent paper by its distinguished secretary.[2]

The Department's headquarters service is now in process of being strengthened by the setting up of an Intelligence and Information Division to advise enquirers on the best means of attacking their research problems and of ensuring that opportunities for applying new knowledge are not lost. This will collaborate closely with the recently formed research department of the Federation of British Industries and with the Joint Research Council of Manchester University and Manchester Chamber of Commerce which is

[1] e.g. in *Nature*, 12 March 1938, pp. 432–5, reviewing the 1936–7 Report; and in *The Engineer*, 10–17 Feb. 1939, reviewing the 1937–8 Report.

[2] Sir Edward Appleton: The work of the Department of Scientific and Industrial Research, *Journ. Roy. Soc. Arts*, 22 June 1945, pp. 372–91.

a possible forerunner of similar bodies at other industrial centres.

NATIONAL PHYSICAL LABORATORY

The National Physical Laboratory at Teddington is regarded as the keystone of the Department of Scientific and Industrial Research, and its work, broadly speaking, falls into the three categories represented by the positions of the rectangles in our endpaper chart: testing, standardisation and research of a fundamental kind, with special emphasis on the precise quantitative expression of scientific relationships.

The testing work [1] is divided into three categories—firstly, tests of routine character and simple type not requiring high accuracy but undertaken by the Laboratory in order to meet the demand that exists for work by an independent body which can ensure an unbiassed certificate of performance; secondly, straightforward tests where the highest accuracy is required, which the laboratory can supply through its experience and its possession of the primary standards; thirdly, tests of an unusual or novel type. Wherever possible the last-mentioned are referred to private consultants so that most of those actually carried out by the laboratory itself are tests which present new features, often to the extent of involving a minor research into suitable methods before the problem can be tackled.

[1] The testing work includes the verification or calibration of thermometers, pyrometers, high vacuum pumps and gauges, X-ray apparatus, optical instruments, electrical measuring instruments and plant, photometry, lighting fittings, gauges, surveying tapes, hydrometers, barometers, clocks, chronographs, taximeters, speedometers, diffraction gratings, pressure-gauges, lubrication, brake linings, etc. A fuller list will be found in the *Report*, from which the above is condensed. In 1937–8 over 530,000 clinical thermometers, 20,000 taximeters and 41,500 other instruments and materials were tested.

Apart from its testing work the National Physical Laboratory, in the words of its *Report* for 1937 : " carried out an extensive programme of researches necessary for the establishment and maintenance of precise standards of measurements, and for the determination of physical constants, in addition to a large volume of investigatory work undertaken on behalf of various Government departments and research organisations ". An idea of the scope of this work can best be given under the headings of the departments into which the laboratory is divided, and it must be understood that what follows below is merely a selection from the items which were in hand in the year before the war.

In the Physics Department, the Heat and General Physics section had then been studying the thermal conductivities of a variety of substances such as air, carbon dioxide, liquid refrigerants, oils used in the quenching of steels, aluminium alloys, micas, building materials and commercial insulating materials for cold stores ; the thermal properties of alloy steels such as their specific heats over wide ranges of temperature, and the quantities of heat absorbed at the transformation points ; also methods for the accurate measurement of the temperature of liquid steel in open-hearth furnaces. In the Sound section a standard objective noise-meter had been developed ; work was being done on architectural acoustics, and an investigation was undertaken of the noise of motor-horns in an attempt to correlate statistically the " annoyance value " (assessed by some 200 listeners of both sexes and various ages), with some measurable physical characteristics of the horns as well as with their effectiveness for their purpose. In the Optics section advances had been made in colorimetry and radiation standards. The Radiology section of the Physics Department, which was conducting researches on the application of

X-rays to crystal analysis, metallurgical problems and other industrial uses, and on the protective value of materials used in X-ray installations, has charge of the British Radium Standard and measures the radium content of samples submitted.

The Electricity Department had been engaged in the development of standards for measuring inductance and, in collaboration with the Chemical Research Laboratory, on high-frequency work to establish the dielectric properties of certain new synthetic resins. Another of its investigations had been into the addition of soaps to dry-cleaning fluids with a view to lessening the generation of static electric charges which, in certain cases, have given rise to serious explosions; meanwhile its Photometry Division had been investigating glare, and the effect of colour of a street-lighting system on the ease with which objects can be detected on the roadway.

The Radio Department had been largely concerned with the application of radio methods to aerial navigation and had collaborated, for instance, in the utilisation of sounding balloons for the study of the upper atmosphere. These balloons carry a wireless transmitting set weighing only 5 lb. which sends out a continuous signal indicating, to a receiving set on the ground, the temperature and the barometric pressure to which it is exposed throughout its journey.

The Metrology Department had been largely preoccupied with routine work such as the checking of gauges for industry but had also made good progress in its own researches including, for instance, the determination of the refractive index of air in visible regions, and the effect of humidity thereon; also the precise determination of *g* at Teddington, a matter of fundamental importance in geodesy and dynamics.

In the Engineering Department attention had been given to the application of X-ray refraction methods for the study of deformations and fracture of metals ; also to lubrication ; wind pressure on structures ; corrosion of metal surfaces in contact and subject to vibration ; the welded construction of pressure vessels ; pipe flanges ; the effect of surface finish on fatigue strength of steel strip ; and (in collaboration with the Physics Department) the silencing of motor-cycles.

In the Metallurgy Department the constitutional diagrams (see page 44 here) of the alloys of iron and of nickel with chromium, etc., had been plotted ; investigations had also been in hand on the creep properties of metals intended for use at high temperatures, and on intercrystalline cracking.

The Aerodynamics Department depends largely on systematic experiments with models suspended in wind tunnels. The largest of these measures 14 feet by 7 feet in section ; another is a high-speed tunnel in which the behaviour of aeroplane wings at air-speeds up to 600 miles per hour can be studied, and there is a compressed-air tunnel with an air jet 6 feet in diameter enclosed in a high-pressure container which enables it to work at a maximum pressure of 25 atmospheres ; by this means air flow can be studied under equivalent conditions covering the whole range from those obtaining in an ordinary wind tunnel to those occurring in actual flight, and scale effect is eliminated.

The William Froude Laboratory possesses two ship-testing tanks respectively measuring 550 feet by 30 feet and 678 feet by 20 feet in which wax models of ships (commonly 8 to 12 feet long) are towed by an electrically propelled carriage which spans the tank and carries instruments to determine the water resistance and other measurements. During 1937 altogether 68 designs of ships were thus tested on behalf of the intending builders ; in 39 of these cases

the designs were improved as the result of the tests so as to obtain reductions in power consumption varying from 3 to over 20 per cent; in the remaining 29 cases the ships had been partly re-designed at the Laboratory before testing so that the amount of improvement by comparison with the original design is unknown. Apart from the testing of designs proposed by shipbuilders a great deal of fundamental research is carried on into such matters as the effect of hull form on resistance; propulsion and pitching of ships in rough water (using wave-producing machinery in the tank); manœuvring of ships; effect of helm on propulsive efficiency; etc., and—with apparatus other than the tank—on problems arising in the design of propellers.

It has recently been stated [98.2] that the continuous research on the resistance to motion of ships carried out in the Ship Division of the National Physical Laboratory over the last thirty years has saved the shipowners about £1,000,000 a year in fuel consumption alone. In future this work will be supplemented by a separate research organisation regarding which see page 117.

The knowledge created through researches in all sections of the National Physical Laboratory is variously published—usually under the names of the members of the staff responsible—in papers before learned societies, articles in the technical press, and pamphlets (also *Collected Researches* every few years) issued by the laboratory itself. An annual booklet of *Abstracts* of all papers originating in the laboratory is also published. The annual *Report* contains a summary of the work in each department, with bibliographical references and the names, grading and qualifications of all the scientific staff, who numbered in 1937–8 over 720.

To this *Report* and to a pamphlet of 20 pages (accompanied by 22 interesting photographs) issued in 1937 under the

title *The National Physical Laboratory—a Short Account of its Work and Organisation* the reader must be referred in order to improve upon the inevitably mis-proportioned summary of a summary which is all there has been room to give here. (See also [83·2] and [83·3].)

In 1945 a Mathematics Division was added, having three sections to deal respectively with computing, statistics and the development of calculating machines.

OTHER RESEARCH STATIONS OF THE D.S.I.R.

The account that can be given of the other Research Boards and laboratories directly maintained by the Department of Scientific and Industrial Research—taking them in the order listed on page 95—must be even briefer, and the same advice holds good : the latest *Report* of whichever Research Board is of interest to the reader should be consulted for particulars, containing as it does summaries of the work of the preceding period and references to the specially published reports as well as to papers and articles in journals in which the results of the investigations are recorded. In addition, several of the Research Boards publish series of abstracts of the literature emanating from all sources in their respective fields of work, and these are included in the table on pages 206–7 of this book.

The function of the Research Boards of the D.S.I.R., and in a more specialised way of the Trade Research Associations described in the next section which work in close touch with them, is generally speaking that of translating fundamental into applied research as suggested by the positions of the rectangles in the endpaper chart.

The chemical work of the D.S.I.R. was at first undertaken at widely separated places under the auspices of a Chemical Co-ordinating Research Board, but in 1929 the

present laboratory close to the National Physical Laboratory was founded. The work there is divided into 10 sections of which some of the most important have related to large-scale researches on the chlorination of methane, the production of formaldehyde and glycerine and of products from fish residue, and high-pressure reactions with special attention to those between carbon monoxide and hydrogen and the formation of higher from lower alcohols. The corrosion of metals is studied in investigations which range from the composition of rust and the velocity and mechanism of its formation to the conditions under which metals are attacked in stagnant or moving salt solutions as in locomotive boiler tubes, water-supply systems and fire extinguishers. The *Report* of this particular institution is triennial and the latest one appeared in 1938.

The Water Pollution Research Board had, in 1938, no central laboratory of its own but carried out surveys through regional committees.[1] That of the River Tees, in which the effect of the discharge of large quantities of sewage and industrial effluents was investigated, led to the discovery that the true cause of the killing of smelts in the estuary is the cyanide in coke-oven effluents, and to a notable demonstration of the possibility of reconciling the community's requirements in regard to pure water-supply with the industrial disposal of effluents. A further investigation of the effect of the crude sewage discharged on the navigability of the Mersey has also been completed.

[1] More recently, reference has been made [98.2] to the existence of a Water Pollution Research Laboratory at Watford with an outstation at Minworth, Birmingham. Dr. Glanville mentions [82.1] proposals for an extended organisation of research in this field which have been put forward by the Institute of Sewage Purification and cites several bibliographical references on the subject. There has also been a paper by J. G. Fowler : Water Pollution Research, *Science and Culture* (Calcutta), Mar. 1944, pp. 367–73.

The Low Temperature Research Station at Cambridge is the main laboratory of the Food Investigation Board. Here the fundamentals of what is practically a new branch of science have had to be evolved, yielding results which are now being applied in the shape of new methods for storing meat, fish and fruit with benefit to the consumer, the home grower and the shipping industry alike. The bacon and pork industry, for instance, are the subject of co-operative work between this station and certain agricultural research institutions, and the canning of food-stuffs is being investigated, including problems connected with the corrosion of tinplate. The causes of decay of meat and bacon, methods of slowing down the chemical processes taking place and the growth of the micro-organisms responsible for it, have been studied; and from these studies there has been developed a system of chilled storage which can be maintained over a period of ten or twelve weeks, which is long enough to ship meat from Australia or New Zealand. In connection with the work on refrigeration, members of the laboratory staff have made voyages in ships to conduct temperature surveys in which the distribution of temperatures throughout the holds and their variation during a voyage are ascertained by as many as 140 distant-reading thermometers electrically connected to a central point. Tests are carried out on the respiration of different kinds of fruit, eggs, meat, etc., under different conditions of storage. A problem which arises when fruit is carried on the same ship as meat is the absorption of flavour from the fruit by the fat of the meat, and on a visit to the station the writer was interested to see samples of meat, which had been experimentally contaminated in this way so as to smell slightly of oranges, which were about to be cooked and then submitted to a " tasting

panel" composed of several members. The Food Investigation Board also operates the Torry Research Station at Aberdeen for fishery problems, where methods have been worked out for the brine freezing of fish over periods of four to six months, as well as improvements in kilns for the kippering of herrings. During the war most of the work on cold storage at either of the establishments has been in abeyance, and investigations have been directed, in collaboration with the Ministry of Food, mainly to the preservation of food by drying. It is now planned to undertake a general comparison between the respective merits of refrigeration, dehydration and canning.

Some extracts from notes made by the writer some years ago on a visit to the Forest Products Research Laboratory at Princes Risborough (since amplified from the publications) may interest the reader as a sketch of how the work there is organised. In the chemical laboratory, research was in hand to determine the actual nature of wood substances, a matter which is not yet fully understood. In the physical laboratory, apparatus was being used to determine the vapour-pressure exerted by the moisture in wood, it having recently been established that the conditions of drying of timber are related more closely to the vapour-pressure than to any other factor. Experiments were also being made to arrive at a standard method for determining the relative smoothness of wood surfaces (see page 61). In the botanical laboratory one saw several hundred specimens of timbers from all over the world which were being used both for fundamental research and for the routine of identifying and describing samples sent in to the laboratory by outside enquirers. In the mycological laboratory specimens of timbers were being subjected to attack by different fungi contained in bottles stored at a constant

temperature, about 30 standard cultures of various fungi being kept alive on agal solution in test-tubes for use in identifying other fungi; work was also being done on wood preservatives. In the entomological laboratory researches were in hand on black beetles and other pests. Rows of tin cans connected up by glass tubes were to be seen, and these the writer was told contained beetles which were being bred under different controlled conditions of humidity in order to determine the conditions which suited them best—the first time that black beetles have been reared in captivity. There is also sound-amplifying apparatus whereby it is possible to tell whether a given sample of wood is infected with micro-organisms by listening to them feeding. The box-testing laboratory, where most of the work is done for commercial firms in return for a fee, has already been mentioned here on page 59. In the wood-working shops experiments are made to determine the best cutting angles for wood-working machinery tools, which are found to have an important influence on the amount of power required, and on other related problems.

At the Building Research Station, again, the foundation is being laid for a new science of building to replace the old traditional knowledge handed down from generation to generation of craftsmen, which the production of new materials and the necessity for speeding up construction have rendered inadequate. Questions not only of materials but also of heating and ventilation, of noise in buildings, and (in a branch establishment at Elstree) of fire resistance are being scientifically studied. Latterly,[82·1] through its collaboration with the Ministries concerned as mentioned here on page 168, the Building Research Station has become an important factor in the plans for post-war housing development, and has erected in this connection a number of

experimental houses. Attention is paid also to problems which are of interest to civil engineers rather than to builders in the ordinary sense, such as pile driving, and soil mechanics extended to problems met with in the making of embankments and drainage cuts like those in the Fen district.

The work of the Road Research Laboratory at West Drayton, Middlesex, is divided into three sections under the respective headings of Soil Mechanics (earthwork and foundations), Materials and Methods of Construction (bituminous and concrete) and Road Mechanics (a heading which includes the study of such phenomena as skidding). Many of the investigations are carried out on behalf of, or in collaboration with, other research organisations. In co-operation with the Ministry of Transport [1] several lengths of experimental road under ordinary traffic are studied with a view to providing information on the relationship between the results obtained in experiments on road-machines in the laboratory and actual performance, and in this way much information is obtained which is useful in many directions other than that which is its main aim. In these correlation tests the collection of weather statistics is an important part of the work, and automatic apparatus has been developed to that end. "Practical applications"—it is stated in the 1938 *Report* of the Laboratory—"must be the aim throughout. This does not mean that all work can or should be directed to immediate practical results. On the contrary it is on the security of knowledge of all the underlying sciences that the usefulness of investigations on specific everyday problems increasingly depends."

[1] This work, in which local authorities all over the country collaborate, is the subject of a separate annual publication (suspended during the war): *Experimental Work on Roads—Report of the Experimental Work on Highways (Technical) Committee, Ministry of Transport.*

At the Fuel Research Station, Greenwich, the better utilisation of coal and its conversion into other forms of fuel are being studied. Valuable work has been done on the improvement of gas-making processes, on low-temperature carbonisation, on the conversion of coal and tar into oil, and on pulverised fuel. The station also forms the headquarters of the physical and chemical Survey of the National Coal Resources which is being carried out in nine laboratories situated in the various coalfields (Birmingham, Cardiff, Chester, Glasgow, Leeds, Newcastle-on-Tyne, Nottingham, Sheffield) and is leading to a fuller knowledge of the numerous varieties of coal available in Great Britain, and their better utilisation. When a seam has been surveyed and the samples taken have been submitted to a great variety of tests its characteristics are plotted on maps wherein the positions of equal properties (such as the content of sulphur and of volatile matter) are joined by lines like contours of height.

The Geological Survey is responsible for the production and revision of geological maps of the whole country and of other data indispensable to mining and water engineers among others. The same Board is responsible for the Geological Museum at South Kensington and for various advisory services centred there.

The establishment of a new organisation under the D.S.I.R. to carry out research and provide advisory service on the control and remedy of infestation of food-stuffs and other susceptible commodities was announced in 1939. Sir Edward Appleton refers in his paper [98.2] to a Pest Infestation Laboratory at Slough which evidently is the outcome of this. (See also the reference to the Cereals Research Station on page 116.) He and Dr. Glanville [82.1] mention also many valuable contributions which the other research stations have

made to the war effort. Thus, models of assault craft of all descriptions and of parts for the Mulberry harbours were tested in the ship tanks of the National Physical Laboratory, whose other divisions likewise helped in a great variety of ways. Methods of enriching proteins with vitamins through the production of food yeast were worked out at the Chemical Research Laboratory. Plywood and adhesives for wooden aircraft were evolved at the Forest Products Research Laboratory. The effects of enemy incendiary bombs on our buildings and of Allied bombs on enemy constructions were studied scientifically at the Building Research Station. Similar researches carried through at the Road Research Laboratory, both on models and semi-full scale, provided the basis for the successful destruction of the Moehne and Eder dams in the Ruhr by the Royal Air Force; and knowledge of the properties of bitumen mixtures accumulated there in the years of peace led to the development of "pre-bitumenised surfacings" for the rapid construction of advanced airfields, as well as of "plastic armour" consisting of a bitumen road surfacing with a backing plate erected around a structure requiring protection, which against certain forms of attack is found to be superior, weight for weight, to steel armour plate.

TRADE RESEARCH ASSOCIATIONS

We now reach a further step in the process of transmuting the work of the academic scientist into forms usable by active industry, by passing from the Government-owned research laboratories to those which belong to associations of the industrial firms themselves, are organised and staffed with direct reference to their problems, and are financed by them with Government aid administered through the Department of Scientific and Industrial Research.

This movement was launched in 1919 when a grant in aid of £1,000,000 was voted to set going the associations and convince industry of the value of research by paying the cost in diminishing amounts until, eventually, it would be borne entirely by the firms enjoying the benefit. Actually the exhaustion of the £1,000,000 fund coincided with the depth of the depression in 1932 and in order to prevent a drastic closing down of valuable researches in hand it was decided to continue Government assistance on the basis of pound for pound of the total subscribed by the industry concerned above a certain fixed datum representing the minimum necessary for upkeep; there is also an upper limit to the Government contribution, at present two-fifths of the total expenditure.

Until the war the annual *Report of the D.S.I.R.* included particulars of the 21 Trade Research Associations then existing, with their addresses, the names and qualifications of their directors of research and secretaries, and a page or two summarising the work of each. The following notes have been abstracted from the *Report* for 1937–8, which is the last to have been published, showing the expenditure of each Association and the main headings under which work was being carried on in that year. Since then, of course, the activities have differed from the normal, and a few notes on the Associations' war work and future plans, derived mainly from [98.2], have been added in brackets.

British Cast Iron Research Association, Birmingham.

£22,360. Graphite refining; high duty and alloy irons; vitreous enamelling of cast iron; moulding sands.

(Much work has been done for Government departments, e.g. on anti-glare appliances for the Ministry of Home Security. Scottish laboratories have been established at Falkirk.)

British Iron and Steel Research Association.

£39,584. Blast furnace; open-hearth furnace; corrosion; heterogeneity of ingots; rolling mill practice; uses of clays.

(Until 1945 this work was conducted by the Iron and Steel Research Council which had been formed in 1923 by the British Iron and Steel Federation. The new Association is a co-operative body which will have a total revenue of nearly £400,000, including £250,000 from within the industry. Besides itself conducting general research it will link the firms' own research centres with one another, with the universities, with users of steel such as railways, ship-builders and constructional engineers, and with technical bodies interested in coal and refractories.)

British Non-Ferrous Metals Research Association, London.

£24,088. Melting and casting of metals; creep; corrosion of zinc coatings; electro-deposition; spectrographic analysis.

(*The Laboratories of the British Non-ferrous Metals Research Association* is the title of a 49-page pamphlet issued by the Association in 1939 describing their new laboratories and the work in hand there. This was briefly summarised in *The Engineer*, 30 June 1939, pp. 794–5. The post-war budget totals £43,000.)

British Refractories Research Association, laboratory at Stoke-on-Trent.

£13,264. Action of slags, gases and vapours on refractory materials.

British Electrical and Allied Industries Research Association, Leatherhead.

£80,121. Dielectrics; earthing; capacity of cables; wear of overhead contact wires; efficiency of steam-power plant; surge phenomena; transformer noise; safety problems; circuit-breakers; interference with broadcasting; fire fighting; rural electrification.

(Budget now exceeds £100,000.)

British Scientific Instruments Research Association, Leatherhead.

£8,184. Durability of optical glasses; tarnishing and corrosion in instruments; level bubbles; glass for gas-discharge tubes.

(War work has included photographic methods for the production of graticules, non-reflecting films on optical components, metallic reflectors by evaporation methods, cements for special purposes.)

Research Association of British Paint, Colour and Varnish Manufacturers, laboratories in Teddington.

£16,641. Paint applications to woods, plasters and metals; difficulties of winter painting; surface characteristics of pigment particles.

Institution of Automobile Engineers (Research and Standardisation Committee), London.

£17,042. Performance of engine bearings; noise in motor-vehicles; deep drawing of metals; cylinder wear, compression ignition engines; cold starting.

(Sections, each with an Advisory Panel, exist for power units, power transmission and vehicle control, vehicle structure, vehicle performance, fuels and lubricants, materials and manufacture, instrumentation. In December 1945 articles of association were signed for establishing a Motor Industry Research Association.)

British Cotton Industry Research Association (including Rayon and Real Silk Departments) Shirley Institute, Didsbury, Manchester.

£95,069. Research, hitherto concentrated on materials for and products of the industry, is now being extended to cover the improvement of machinery and equipment.

(During the war the Association produced a waterproof cotton cloth by so twisting the fibres that on contact with moisture they would swell and block the interstices without other treatment. This was used for hose-pipe and for garments for airmen liable to be immersed in sea water.[98.2]

It was announced at the end of July, 1945, that the D.S.I.R. is granting this Association £30,000 a year for five years if the industrial income reaches £70,000, with a further £ for £ grant on all industrial income over this amount to a maximum of £50,000. The capacity of the Shirley Institute is thereby to be doubled and its scope extended to fibres other than cotton, and an engineering department is to be set up which is expected

to exert considerable influence over the design and development of textile machinery.)

Wool Industries Research Association, Leeds.

£24,405. Chemical treatments to produce shrinkage resistance; alternatives to olive oil as wool lubricant; combinations of rubber and wool; fibre-length distribution and sampling errors; mechanical processes.

Linen Industry Research Association, Lambeg, Northern Ireland.

£20,439. Spinning, weaving and bleaching problems; lustre photometer.

(Departments exist for spinning, weaving, chemistry, testing and liaison. Strains of pedigree flax have been evolved whereby the yield per acre is increased by over 50 per cent.)

British Launderers Research Association, London.

£10,761. Detergent solutions; washing of woollens by machine; bacteriology, hydro extractors.

(Wartime researches have led to savings of 40 per cent in rationed soap and the processes so developed will be of permanent value. The Association co-operated in the standardisation of shrinkage limits for textiles.)

British Leather Manufacturers Research Association, London.

£15,470. Curing and storing of market hides; greasing of belting leathers; tanning processes; pigment finishes.

British Boot, Shoe and Allied Trades Research Association, London.

£5,878. "Walking research": see page 51.

(A post-war research scheme is proposed which would cost £40,000 per annum, the D.S.I.R. finding two-fifths. Problems envisaged include foot statistics and their application to the retail trade; measurement, identification and recording of feet; last design; materials and shoe manufacture; stocking of retailers; physiological effects; shoe repair.)

Research Association of British Rubber Manufacturers, Croydon.

£12,081. Durability of rubber jointing and flooring; other ageing problems; whiteness measurements; testing.

Research Association of British Flour Millers, laboratory in St. Albans.

£13,148. Definition of baking quality in terms of physical properties of dough; instruments for measuring this; control of gassing power of flour; milling processes; wheat conditioning; nutritive values.

(Became, under the name of Cereals Research Station, the headquarters for research on flour and bread under the Ministry of Food.)

British Association of Research for Cocoa, Chocolate, Sugar Confectionery and Jam Trades, Leatherhead.

£9,336. Resistance of cocoa butter to oxidation changes; pectin formation; uses of gelatin; toffee manufacture; storage; variations in sugar.

(121 reports have been produced on such subjects as "bloom" and other defects in chocolate; prevention of mould and fermentation on jams; fundamental principles in the manufacture of confectionery; keeping qualities thereof; jellying and granulation of jams; insect infestation.)

British Food Manufacturers Research Association, Leatherhead.

£4,000. Bacon and hams; meat products; fish products; corrosion of cans. (Shares accommodation with the last mentioned.)

Printing and Allied Trades Research Association, Leatherhead.

£10,301. Properties of paper and ink in relation to printing qualities; fading of posters and showcards; corrosion of foil papers; warping of book covers.

(Now has both a Printing and a Packaging Division.)

British Colliery Owners Research Association, London.

£4,158. Co-operative work with the Safety in Mines Research Board on suppression of dust, atmospheric conditions in deep mines, etc.; underground illumination.

British Pottery Research Association, Stoke-on-Trent. Founded 1937.

£4,562.

(Researches are directed by panels for earthenware, tile, china, jet and rockingham, sanitary fireclay, sanitary earthenware, electrical porcelain, kiln and saggar. Resulting papers have appeared in *Trans. Br. Ceramic Soc.*)

The total of the expenditures in 1937–8, as itemised above, was £450,892. The estimates for 1945–6 totalled £423,400, and for 1946–7 they are £860,600, including £200,000 for capital grants. Now, after the war, a very considerable increase is to be expected, as many of the existing associations are planning to embark on longer range work and to spend at least double. Moreover, since 1938 additional research associations have been established for shipbuilding, gas, coke, internal combustion engines and paper, whilst several others are under consideration.

The British Shipbuilding Research Association is to be governed by the Shipbuilding Research Board on which the various scientific interests concerned are represented, this Board being responsible to the Shipbuilding Research Council elected by the Shipbuilding Conference. Its work will complement that of the Admiralty, of the National Physical Laboratory (page 103) and of the Classification Societies (page 173) being concerned with questions of standard nomenclature, tonnage regulations, recording of ship performances, structural design and fittings, electric welding, cargo handling equipment, deck coverings, plastics, propelling machinery, steam reciprocating engines, Scotch boilers, water tube boilers, steam turbines, diesel engines, diesel and turbo-electric drive, the gas turbine, auxiliary engines and equipment, and propellers.[1]

"The policy and scope of the Gas Research Board" was described by E. V. Evans in a paper under that title

[1] W. Ayre: The Shipbuilding Research Association. *Shipping World*, 26 April 1944, pp. 443–9.

before the Institution of Gas Engineers[1] whose research work, with that of others, the Board has taken over and will continue at a cost of some £400,000 a year.

The British Coke Research Association, formed in 1944, will develop and co-ordinate the work of existing Midland, Northern and Scottish Coke Research Committees.

The British Coal Utilisation Research Association, supported by the Mining Association of Great Britain, was formed in 1938 to take over the work of the Combustion Appliance Makers' Association (Solid Fuel). It is co-ordinated with the Gas Research Board, the British Coke Research Association and the Fuel Research Station of the D.S.I.R. by a Standing Conference under the chairmanship of Sir Harold Hartley. During the war it co-operated with I.C.I. Ltd., Vauxhall Motors Ltd. and others on producer gas plants for internal combustion engines and with the Ministry of Fuel and Power on heating appliances and other developments. Its laboratories are at Leatherhead.

The British Internal Combustion Engines Research Association was started in 1943. The British Welding Research Association was formed in March 1946 to take over the work of the Welding Research Council and is expecting to spend £25,000 a year.

Six of the Research Associations, it will be noticed, have their laboratories at Leatherhead. There they share a common site on which it has been remarked : " One of the advantages of a university arises from informal discussions, often over a luncheon table, and similar opportunities will occur in this colony of scientific workers. Pooling of

[1] Reprinted in *Gas Journal*, 10 June 1942, pp. 400–8. For a brief account of earlier research work under this Institution see *Journ. Inst. C.E.*, March 1939, pp. 385–8.

library resources and common translation services should also be possible economies."

The associations are autonomous and voluntary, all British firms in the respective industries being eligible and the programmes of research being planned by governing councils elected by the member firms. The amount and manner of levying the subscriptions vary but it is claimed that a payment less than the wages of a good office-boy entitles a firm of average size to the benefits of an organisation spending thousands of pounds a year on research. Generally speaking, the privileges of a member firm are to put technical questions to the expert staff of the association, to recommend specific subjects for research, to use patents resulting from the work without charge or on reduced terms, to have particular investigations for individual benefit carried out at cost price, to receive confidentially the results of research, and to utilise the documentation services organised by the association. Some of the publications are made generally available, others are confidential among the member firms.

The value of this arrangement of conducting research through associations instead of by individual firms lies largely in the fact that it provides the most economical, if not the only, way for the small firms to have researches carried out, keep abreast of technical progress and secure scientific advice—and even now it is the smaller concerns that form the backbone of British industry : a survey some years ago showed that over 117,000 of the 128,000 factories in the country employed less than 100 workers each and less than 500 works employed more than 1,000 each. At the same time both large and small firms benefit by the pooling of resources to solve those problems which are common to the whole industry, and indeed experience

shows that frequently it is the firm with the best research staff of its own that is able to make the best use of the results obtained by the research association.

As to the value of such research two examples out of many must suffice. The British Refractories Research Association spent £8,600 on research devoted to the replacement of saggars (refractory casings in which pottery is baked) and the resulting *annual* saving to industry is estimated at £150,000. The improvement of 40 to 44 per cent in the efficiency of steam-generating stations realised between 1928 and 1937 is attributed largely to the work of the British Electrical and Allied Industries Research Association; on the output of units of electricity sold in 1935 the higher efficiency represents a saving in coal of more than £7,000,000 or an average spread over the ten years of £700,000 per annum, and only 10 per cent of this need be credited to the association to cover the whole of its annual expenditure on all its researches. "It is doubtful whether any other expenditure in the national budget brings in anything like the same return as the £600,000 expended by the Department of Scientific and Industrial Research" through its own laboratories and those of the research associations it helps to support.

In 1937 the Association of Scientific Workers (see page 348) put forward to the Lord President of the Council a Memorandum on the Finance of Research in which it was proposed that a fund of £30–£50 millions should be set up and vested in a corporation on the lines of the Electricity Board, out of which research was to be endowed according to a budget determined some years ahead instead of the income available for it fluctuating, as at present, with the prosperity of industry. It was also proposed that 20 new industrial research associations, seven new institutions for

fundamental research and six new research boards with co-ordinating functions should be set up. The scheme, and the grounds on which it was rejected, were published in full in *The Scientific Worker*, November and December, 1938. The library resources of most of the Research Associations are accessible via the National Central Library : see page 225.

DEFENCE SERVICES

Even before the war the heaviest Government expenditure on technical research was that which arose in connection with the three fighting services, though much of the knowledge so obtained was of value for civil purposes also. For instance, the Navy Estimates for 1938 included £766,880 for Scientific Services, covering among other items the upkeep of the Royal Observatory, Greenwich,[1] and another astronomical observatory at the Cape of Good Hope ; also £227,640 out of this total for the Hydrographic Department which is responsible for survey work and the production of charts. Most of the balance was for work controlled by the Director of Scientific Research and Experiment who has under his direct charge the Admiralty Research Laboratory at Teddington (for fundamental researches not needing a sea environment in their early stages) and the Admiralty Engineering Laboratory at West Drayton (concerned with such developments as the marine oil engine and other naval engineering work, metallurgical and other connected problems, and, in a separate section, electrical machinery and cables) ; in addition he acts in a consulting and co-ordinating capacity to other Admiralty departments and provides, from a central pool, the civilian scientific staff for experimental work under their respective heads. These departments

[1] Now to be moved to Hurstmonceux Castle, Sussex.

include the Haslar Experiment Works which are engaged under the Director of Naval Construction in investigations on the resistance and propulsion of ships and similar problems ; the Mine Design Department ; and the Signal School at Portsmouth. In this last the training of officers and men of the Signal and Telegraphist Branches is carried out side by side with the experimental development of their equipment ; scientific discoveries which appear applicable to fleet communications and to certain problems of navigation are evaluated and if found suitable are developed through laboratory work and sea trials into a practical form. In the same way the anti-submarine establishment at Portland provides both for training and for experiments in the use of anti-submarine material and of the echo-sounding system used for navigational and hydrographic survey purposes.

The Army Estimates that year included no less than £1,125,900 in respect of " Establishments for Research, Experiment and Design " of which the largest is the Research Department, Woolwich, dating back in lineage to 1683. The latter was to cost £458,710 to which the Admiralty, Air Ministry and D.S.I.R. contribute nearly one-half on account of work done for them ; much of its work (in metallurgy, for instance) leads to improvements in industrial processes which are valuable for civil purposes. It is controlled mainly by the Ordnance Board, " a body of experts dealing with the construction and efficiency of guns, small arm ammunition, and explosives and with progress in the science of artillery and small arms ". The Experimental Establishment at Shoeburyness, costing £104,980, to which the Admiralty and Air Ministry contributed £79,000, is concerned with the proof of armour plate, guns, projectiles and cordite. Other centres exist for anti-aircraft, signals and Royal Engineer work. The Chemical Defence Research

Department at Porton and Sutton Oak, costing £135,470, also does work for civil departments.

The Air Ministry, in the same way, was budgeted to spend £623,000 on Experimental and Research Establishments of which the largest is the Royal Aircraft Establishment at Farnborough costing £459,500.

A separate vote of £351,500 represented expenditure administered by the Air Ministry as much for civil as for Royal Air Force purposes, namely that on Meteorological Services. These included the recording, collection, interpretation and publication of observations from all over the country, collaboration with similar services abroad, advice on meteorological matters for civil aviation, and original research in meteorology and geophysics.

Since the above was written scientific work in support of the fighting services has, of course, greatly extended, but no details of the war-time expenditure thereon have yet been published, nor is it clear what proportions it will assume after the war. Organisationally, perhaps the most important change has been the setting up in 1939 of the Ministry of Supply which among other responsibilities took over all those previously held by the War Office and the Army Council in reference to design, inspection, research and experiment. The new Ministry has carried out research through some 18 establishments, as well as extramurally, under the direction of its (1) Controller General of Munitions Production acting through Director General of Scientific Research and Development (under whom about a thousand scientists and engineers were, at one time, employed), (2) Senior Supply Officer responsible for Armaments Design Department, Armaments Research Department and Ordnance Board, and (3) Chairman of Armoured Fighting Vehicles Division. The Army con-

tinued to be the Ministry's main " customer ", but much work has also been performed for the other fighting services and Government departments. In April 1946 the Minister of Supply set up a Machine Tool Advisory Council to provide a means for regular consultation between the Government and this industry in the interests of national defence and industrial efficiency. A similar council will be established to deal with the gauge and tool industries.

The Ministry of Aircraft Production, separately constituted early in the war, has now been merged in the Ministry of Supply. Among the many important organisations which it developed has been the Radio Research Board directed by the Controller of Communications Equipment. To improve the quality of aircraft an Aeronautical Research Committee was formed under the Air Ministry, composed, with its sub-committees, of both Government and non-official scientists.

In August 1946 the news was released of a very large aeronautical research station under construction by the Ministry of Supply near Bedford.

In all three services still larger sums than on research are spent on the highly technical work involved in the inspection of materials purchased from contractors ; moreover in these days of mechanisation the combatant training of officers and men is itself largely a matter of imparting and developing engineering knowledge of one kind or another. In the Army this culminates at the Military College of Science.

During the war many thousands of officers were employed operationally in the expanded technical services of the Royal Navy, Army and Royal Air Force and in new corps such as the Royal Electrical and Mechanical Engineers (developed from a section of the Royal Army Ordnance Corps and other existing elements).

The Times of 4 May 1945 printed an interesting two-column article from a Military Correspondent under the heading "Foundations of Defence—Continuous research required in peace time—The training of technicians" in which the following extract was quoted from the report of the Royal Commission on the Manufacture of Armaments in 1936:

> We recommend further that the Government's own manufacturing establishments should be fully equipped for the production in some measure of naval, military and air armaments, that they should be responsible for the training of technical experts, take the initiative in the production of designs and improvement of machine tools and the formulation of mass-production methods not only for their own manufacturing requirements but for the use and instruction of the private industry of the country in time of emergency.

The correspondent goes on to explain that this policy of organising Government establishments as ever ready cadres and nuclei of everything that is necessary for rapid expansion by private firms is likely to be maintained in the future, because two major wars have taught us these lessons: Firstly, "the impact of impending war falls first on the technical staffs, since provision of weapons takes longer than the training of men". Secondly, "in total war most issues can be judged by their ultimate effect on the expenditure of man-power, whether in the services or in the factories, and there is no surer way of squandering man-power than by skimping development and supply organisations".

ATOMIC RESEARCH

That man's discovery of his power to release nuclear energy should have been applied, before all else, to war, is perhaps the greatest tragedy and most sobering reflection in

the whole history of science. This having happened, but the hope being left that we shall learn to use such energy for our good instead of for our destruction, the most fitting point in this book at which to insert a brief note on the subject would appear to be here, between the sections which deal with Government-sponsored research applied to war and applied to peace.

In this country the first public reference to atomic bomb research was made by Mr. Winston Churchill in a statement issued on 6 August 1945 immediately after the first such bomb had been dropped by American aircraft over Hiroshima. The statement (which like those quoted below appeared in *The Times* and other newspapers next day) disclosed that as early as 1939 researches co-ordinated by a committee under the Ministry of Aircraft Production had been proceeding at a number of British universities ; that in 1941 a special division of the D.S.I.R., known by way of a blind as the Directorate of Tube Alloys, had been set up to handle the matter and that later in the same year a pooling of British and American fundamental researches in atomic energy had been achieved. A number of the British scientists concerned had then joined their colleagues in the United States, where the vast and very highly capitalised engineering developments needed for bringing the bombs into production took shape under American control.

After victory, on 3 March 1946, Mr. Attlee as Prime Minister referred to the research on atomic energy currently proceeding in British universities. Such research, he said, is not limited by financial considerations, but by the numbers of trained men of science and of material resources available. Expenditure on the programme for the year 1946–7 was estimated at £2,800,000.

On 28 March 1946 Mr. Wilmot, Minister of Supply and

of Aircraft Production, made a longer statement in the House of Commons. Notwithstanding that the United States were more fully seized than ourselves of the technical " knowhow ", the prospects of this country were, he said, very bright in work to which British scientists had made an immeasurable contribution. In the present state of knowledge it was doubtful if the achievements of the next ten years could result in widespread industrial applications. When these came, it was more likely that atomic energy might be converted into electrical power, by means of steam or gas turbines, in big rather than in small units. Ship propulsion was another possibility. Apart from the generation of power, the artificial production of radio-active minerals to replace X-rays and radium might be industrially valuable.

As this book goes to press a Bill is being brought before Parliament placing the development of atomic energy under public control and public ownership through a Board responsible to the Ministry of Supply and Aircraft Production. Powers are to be taken under the Bill to set up nuclear energy research stations. One at Didcot will employ some 500 technicians and scientists ; one at Risley, Lancashire, 300 ; a third at Springfield, Lancashire, for the processing of materials may need as many as 1,000. The Bill will bring this country into line with the United States and U.S.S.R., carrying out British obligations under the United Nations resolution on atomic energy earlier in the year, whereby an international Atomic Energy Commission is being set up, with which the Ministry of Supply will be the British link. Springfields, near Preston, had been chosen as the site for a subsidiary plant for processing materials.

In March 1946 H.M. Stationery Office published a reprint of the *Report on the International Control of Atomic Energy*, issued in Washington by the U.S. State Department in the

previous month, which refers to the problem of rendering the new scientific mastery of nuclear fission safe for the world. Hitherto, most schemes for control have assumed that all nations would be left free to carry on research and development in this field subject to an international system of inspection with police functions to see that developments do not take the direction of atomic weapons, which would be outlawed. A purely repressive system of this kind might well, however, defeat its purpose by leading straight to international rivalries and friction, and another way is preferred. "Uranium isotope 235" and plutonium, the possible practical sources of nuclear energy, can be what is called "denatured": that is, mixed with some inert substance that slows up the reaction sufficiently to render it useless for explosive but not for peaceful purposes. Removal of the denaturing substance is, like the mining and refining of the original minerals, a difficult process involving large installations which would be difficult to conceal. The proposal is, therefore, that an international Atomic Development Authority should be set up which would itself conduct research to ensure its being as well informed on atomic matters as any individual nation and which, so equipped, would control throughout the world the supply of fissionable minerals and their sale, in the denatured state only, to national plants licensed by it to use them.

A guarded American official account of developments to date was republished by H.M. Stationery Office in 1945 under the title *Atomic Energy*.[1]

An Atomic Scientists' Association has been formed with headquarters at University College, London.

[1] H. de W. Smyth: *Atomic Energy for Military Purposes* (Oxford Univ. Press, 1946) amplifies this with official statements on the British and Canadian contributions.

LABORATORIES OF OTHER GOVERNMENT DEPARTMENTS

The General Post Office maintains a large research station at Dollis Hill where fundamental work is done, especially (but not exclusively) in connection with the development of tele-communications and related problems in acoustics, electric cables, metallurgy and the testing of materials. In a reference[1] to the opening of the present laboratories in 1933 it was stated that the annual saving to the Post Office effected by 14 of the 511 investigations completed in the preceding year amounted to £190,000 and that at the same time 1,700 students destined for the G.P.O. engineering service were being trained.

The British Broadcasting Corporation has an Engineering Research Department in which seven Senior Research Engineers head sections dealing respectively with acoustics, recording, transmitters and aerials, field strength and propagation, receivers and radio frequency measurements, audio frequency microphones and loudspeakers, and special studies.

The National Institute of Agricultural Engineering at Askham Bryan, near York, is maintained by the Ministry of Agriculture and Fisheries, advised by the Agricultural Machinery Development Board which was appointed in 1942. It issues the *Agricultural Engineering Record*, "a quarterly review of developments in farm mechanisation with a summary of official test reports".

The Government Laboratory in London, which has a staff of 72 chemists, originated in a laboratory set up in 1842 at Somerset House to check the adulteration of tobacco and was constituted in 1911 as an independent department under the Treasury having its own Parliamentary vote entitled "Government Chemist". It exists for the purpose of

[1] *Nature*, 28 Nov. 1933, p. 670; and *Engineering*, 20 Nov. 1933, pp. 471–2.

affording advice and assistance on chemical matters to the various departments of state, but does not undertake work for private interests, nor is it intended for original researches. The duties now include analysis of spirits, beer, sugar, tobacco, etc., for the Revenue authorities in addition to work for the Geological Survey, the War Office, the Ministries of Agriculture, Food, Health and Supply, and the Board of Trade. An annual *Report* is issued.

LABORATORIES OF INDUSTRIAL CONCERNS

> However successful co-operative research may be [observes Sir Edward Appleton [98.2]], it can never be generally expected, especially in short range research, to obtain results more quickly or to be more profitable than research carried out in a firm's own research department, with a staff in a position to appreciate the firm's problems to an extent impossible to any outside organisation. . . . Government has taken the only means available for encouraging private industrial research by the substantial remission of taxation on research expenditure announced in the last Budget.

Hundreds of laboratories of every size and variety exist for the purpose of developing and applying scientific knowledge in relation to the work of individual firms and public services in a more specialised and self-interested way than is done by the collective associations already described, as well as for the control of actual production and the elucidation of customers' problems in the use of the products. Sometimes, also, groups of firms arrange to collaborate in research[1] without going to the full length of setting up an association under the ægis of the D.S.I.R., or agree to exchange research information.

The total numbers employed and amounts spent by industrial firms on research is not accurately known,

[1] An interesting new organisation of this type is the Therapeutic Research Corporation (*Engineering*, 2 Jan. 1942, p. 12).

but apparently [76·1] some 3,000 scientists are so engaged and the total expenditure on research and development work by industrial firms is of the order of £2,000,000 per annum. Other estimates range as high as £10,000,000 ; the variation may probably be explained by the difficulty of drawing a hard and fast line between research and routine investigations and testing. Here a quotation from the article on " Research —Industrial " in the *Encyclopædia Britannica* by the late Sir Richard Glazebrook may be illuminating :

> In any modern factory a laboratory of some sort is essential, to check the purity of the material employed and to ensure that the product is up to standard. . . . But such work is not research, though often it may indicate where research is necessary and lead up to original investigations of high value to the firm. The works manager knows that for success the temperature at some point in a complicated process must be kept within narrow limits, whereas during other operations large variations of temperature have little effect. Samples which fail come to the works laboratory for examination, and enquiry shows that the temperature limits at this critical stage have been exceeded. Such an occurrence naturally needs a competent chemist to enquire what is the nature of the action which has taken place at this critical temperature. But how does the product, . . . when the temperature limits are overstepped, differ from the proper article ? This enquiry may lead to a long and intricate investigation with results of the utmost importance to the firm. It may be found, for example, that a slight change in the composition . . . will render the close limits unnecessary, will reduce greatly the care and attention required to the manufacture. The problem has become one for industrial research, not merely for routine testing, and the consequences of that research have proved to be the simplification of manufacture and cheapening of the product.

A lecture by Dr. L. H. Lampitt on *Laboratory Organisation*, printed by the Institute of Chemistry in 1935, gives a good idea of the arrangements in and daily work of an industrial chemical laboratory, evidently that of J. P. Lyons & Co.

Ltd., concerned mainly with the sampling of a great variety of food-stuffs. Much of it is of wider application. A shorter but more recent account of the same laboratory is included in[199.1] which states that it was founded in 1919 and now has a staff of over 200 of whom half are graduates. Its functions are (1) chemical and bacteriological examination of raw materials, food in process of preparation and cooking, and the finished product to ensure that all shall be of the highest possible purity; (2) to control working processes so as to prevent waste and produce a standard product (see page 64); and (3) to advise on new materials, new plant and new processes.

Individual works laboratories are described from time to time, with indications of the scope and organisation of their work, in articles in the technical journals, and the reader cannot do better, perhaps, than look through the indexes extending over a few years back to find examples of any particular kind in which he is interested. On page 133 are some random references found in this way.[1]

To expand the first of these references a little by way of example, the research laboratories of Pilkington Bros. Ltd., built at a cost of about £40,000, were opened in 1938 with a staff of 47, including some 15–20 graduates. Working in close touch with the general analytical laboratories of the firm, they were to reach back to more fundamental investigations falling into seven categories: the melting of glass, the study of refractories, the processing of glass, its uses, its properties, methods of testing glass, and miscellaneous matters such as the production of mirrors to withstand rigorous weathering and temperature conditions.

[1] *Science Library Bibliographical Series*, No. 414, 1938 (gratis), gives references to over 200 articles published during the period 1928–37 describing industrial research laboratories.

Kind of Work.	*Name and Place.*	*Article in:*
Glass technology . .	Pilkington Bros. Ltd., St. Helens	*Nature*, 22 Nov. 1938
Water examination .	Metropolitan Water Board	*The Engineer*, 21 Nov. 1938
Electrical testing . .	General Electric Co. Ltd., Witton	*The Engineer*, 13 Mar. 1936
Electric cables . . .	Callenders Cable Co. Ltd., Erith	*Engineering*, 6 July 1934
Electrical research . .	General Electric Co. Ltd., Wembley	*The Engineer*, 5 July 1935
Hydraulics	Electroflo Meters Co. Ltd., Park Royal	*The Engineer*, 3 Apr. 1936
Hydraulic turbines .	English Electric Co. Ltd., Rugby	*Engineering*, 25 Dec. 1936
Metallurgical research	Mond Nickel Co. Ltd., Birmingham	*The Engineer*, 30 Oct. 1936
Use of plastic materials in aircraft construction	Aero Research Ltd., Duxford	*Engineering*, 9 Oct. 1936

Imperial Chemical Industries Limited consists of a number of separately managed but financially grouped manufacturing divisions—Alkali, Dyestuffs, Explosives, Fertilisers and Synthetic Products (now known as the Billingham Division), General Chemicals, Leathercloth, Lime, Metals (non-ferrous), Paints, Pharmaceuticals, Plastics, Salt—each of which conducts its own research but is co-ordinated by a central department.[1] When the war began there were

[1] The establishment of a laboratory near Welwyn for long-term general and academic research transcending the interests of the divisions was announced in August 1946. Here the subjects of study will include antibiotic products of moulds, kinetics of continuous chemical reactions, deformation of materials under high stresses of short duration, design of industrial instruments, industrial toxicology.

18 research laboratories in all, which employed staffs of over a thousand and represented a capital investment of £860,000. In 1937 the Chairman—from whose successive annual addresses to the shareholders, printed in the *Financial Times*, this information is quoted—gave the total expenditure on account of research as £6,000,000 in ten years. So remunerative has the investment in research proved to be, and such was the stimulus afforded it by the war, that by 1943 the expenditure on research and development had increased to £2,200,000 in a single year. The resulting gains have increased in even greater proportion. They have included, on the one hand, improvements in manufacturing processes which have enabled increased outputs without which the war might well have been lost: metals vital to the Allied Navies produced in quantities half as great again as before the war; fertilisers in double the pre-war quantities; explosives out of all proportion. And they have provided the key for turning many new discoveries into actualities—discoveries like the Piat weapon for use by infantry against tanks and fortifications, and others of equal value in war and peace, such as Atebrine, Mepacrine and Penicillin; new toxic chemicals for pest control; the soup-heating cartridge; plastics applied to optical uses and as flexible insulators for electric cables; paints and lacquers for every purpose.

These are fruits of research activities stimulated by the pressing demands of war; but in their essence those activities are no different from in peace, and the note which appeared in the original edition of this book may still stand.

Firstly, there is the improvement of the efficiency of the manufacturing plants: research workers study the physical and the chemical conditions in a plant perhaps for weeks, and then carry out experiments either on the plant or more often in the laboratory to see how the process may be

improved. Secondly, there is the control of the economy of the processes and of the quality of the products by analysis which, although largely reduced to a routine, is continually giving rise to new problems which call for research in order to evolve new methods which shall be more accurate, simple or expeditious than the old. Then there is the research known as Technical Sales Service to customers, on the lines already mentioned on page 78. Again, research is carried on to evolve new products or new methods of manufacturing existing products, and a proportion of the expenditure is devoted to research of a fundamental kind in which no immediate commercial objective can be formulated.

To quote an example from a different field, the research department of the London, Midland and Scottish Railway [1] has developed from a small chemical laboratory set up in 1864 which was mainly concerned until recently with the routine analysis of materials purchased by the company. The department now comprises five chemical and one physical laboratory at various points and a large modern laboratory opened in 1935 at Derby with sections for engineering research, metallurgy, paint and textiles, staffed by some 70 university graduates. The functions of the laboratories have far outgrown their original purpose of routine analysis and testing, their personnel being now in effect equipped to act as scientific consultants to the other departments and particularly to assess by scientific measurements the properties of materials or the behaviour of appliances, enabling decisions of the departments concerned

[1] Sir Harold Hartley, paper before Institute of Transport, extract in *Modern Transport*, 16 Apr. 1938, p. 3. See also the chapter on research in J. W. Williamson: *A British Railway Behind the Scenes—a study in the science of industry* (London: Benn, 1933).

to be founded on accurate and impartial facts. In addition, research of a more fundamental kind is carried out whenever there is need for a material product or a process which has not been available previously; for instance, a special paint has been produced for treating the water troughs from which locomotives obtain water en route, with the object of suppressing the growth of algæ which formerly required frequent removal by hand to prevent interference with the action of the injectors on the locomotives. Again, a part of the work of the physics section relates to problems in the lighting, heating, ventilating, air-conditioning and sound-proofing of passenger trains—questions which involve many observational measurements both in trains and in buildings.

ORGANISATIONS CONCERNED WITH PRODUCTION AND PERSONNEL

The Institution of Production Engineers was founded in 1921, and its research department began, in 1938, its work of "investigation to discover facts and laws relating to the planning, control and execution of processes by which material is given a predetermined form with the aid of machines, tools and labour". This definition is quoted from its brochure *Production Engineering*, published in 1944, which gives illustrative examples and refers to various other resulting publications, dealing mainly with machine tools. The Institution issues a monthly *Journal*.

The interests of the National Institute of Industrial Psychology are very readably described in a book by the director of its Scottish Division, C. A. Oakley: *Men at Work* (London: Hodder & Stoughton, 1945).

The purpose of psychological (and physiological) tests may be explained by analogy with page 45 of the present

book where reference was made to the advantage of being able to define objectives and measure the characteristics of the available means in the same terms, so as to be able efficiently to match one against the other. This principle, now accepted as a matter of course as regards physical material, the N.I.I.P. is engaged in extending to human material. Occupations, both manual and professional, are analysed to distinguish and ascertain what inherent mental qualities they demand as a pre-condition for the acquirement of skill—for instance a motor driver needs consistently quick reactions, ability to distribute his attention, and various other qualities—and " batteries of tests " are worked out which will serve to check the presence or absence of these qualities in untrained persons. One important use of such tests is in the vocational guidance of young persons (a service which the institute provides in return for a small fee) and another is in enabling " accident-prone " individuals to be detected in advance and excluded from those occupations where they would be dangerous. The success of such work is gauged in a perfectly detached and unprejudiced way by statistical analysis of the after-histories of persons tested : when a high degree of correlation is found to exist between their performance in the preliminary tests and the degrees of efficiency and freedom from accidents they afterwards attain the forms of test are standardised ; if not, these are modified and progressively improved.

The institute's work is by no means limited to psychology in the ordinary sense of the word but extends to all interactions of the physical with the human. It maintains a staff not only of psychologists but of experts in heating, ventilating, lighting and workshop and office organisation who are available to inspect and make recommendations regarding industrial and other establishments of every

variety. The following example from among the many appended to the *Annual Report* for 1938 may serve as illustration :

> *Dyers and Cleaners.* Especially during the summer, the workers in a dry-cleaning factory were found to suffer considerable discomfort owing to the heat from their presses. An investigation was therefore carried out to discover whether the main discomfort was due to radiant heat, to convected heat or to humidity. Experiments were made at the Institute's headquarters to determine the most satisfactory method of lagging presses. The improvements recommended by the Institute were adopted by the firm who also, at the Institute's suggestion, provided suitable cooling drinks for their workers. Further investigations concerning the selection and training of branch staff and the selection of office staff are in progress.

The Institute maintains a library and publishes a monthly journal, *Occupational Psychology*, as well as two monthly bulletins. The July 1946 number of this journal, marking the Institute's twenty-fifth anniversary, contained addresses reviewing its work and its relation to cognate bodies, as well as one on " The Army's use of psychology during the war ".

Researches of much the same kind are carried on in the Department of Industrial Physiology of the London School of Hygiene and Tropical Medicine, under the auspices of the Ross Institute Industrial Advisory Committee which was formed in 1928 " to keep industry in touch with science, to make the tropics healthy, and to expand the markets of the world ". This institute, like the foregoing, organises instructional courses for persons concerned in factory administration and others.

The Industrial Health Research Board (which was formerly the Industrial Fatigue Research Board, and is connected with the Medical Research Council) is the source of many valuable publications. A bibliography of these and

particulars of the organisation, together with a summary of research findings applicable to the national effort, appeared in 1940 under the title *Industrial Health in War.*

It may be mentioned here for convenience that several societies concerned with the collative study of various aspects of management, including the Institution of Engineering Inspection, are grouped under the Confederation of Management Associations whose monthly journal, *Industry Illustrated*, refers to their activities and interests.

Late in 1945 the President of the Board of Trade appointed a committee to frame detailed proposals for a British Institute of Management with Government support.

CHAPTER FOUR

BRITISH COLLATIVE ORGANISATIONS

INTRODUCTION

In this book the term "collation" is used to mean the putting together of elements of knowledge to produce new knowledge; a thing which is made possible by publications and "documentation" and is aided by the machinery of committees and conferences of experts to discuss ideas put before them which was sketched in the concluding sections of Chapter One.

The organisations [1] which provide this machinery and are now to be described usually perform other functions also, the emphasis varying widely between the one extreme of "learned societies" and congress-holding associations concerned with science as such; the middle ground of "professional institutions" concerned both with science and scientists in their particular spheres; and the opposite extreme of associations whose declared aim is to promote certain economic interests and which concern us here only in so far as they yield technical knowledge as a by-product of doing this.

In order to be able to bring out these variations in emphasis when referring to particular organisations it will be convenient first to enumerate the whole range of purposes

[1] The *Official Year-Book of the Scientific and Learned Societies of Great Britain and Ireland* (London: Griffin) gives half a page or so of particulars of each, including the names of the principal officers, publications, etc.

which such a body is capable of serving, it being understood that few if any organisations combine all of them :

(*a*) To conduct researches through committees and publish the resulting reports.

(*b*) To provide for the critical discussion and subsequent publication of individual scientific papers.

(*c*) To assist individual researchers by the provision of library and other facilities such as the indexing and abstracting of technical literature.

(*d*) To assist technical education.

(*e*) So to control the admission of members (by examinations, conditions as to experience, etc.) that membership in itself comes to be regarded by everyone as an attestation of professional standing.

(*f*) To express the corporate opinion of a particular profession or interest on questions of public import, or in relation to other bodies, when occasion arises.

(*g*) To regulate professional ethics.

(*h*) To promote the economic interests of members.

UNSPECIALISED LEARNED SOCIETIES

The Royal Society stands in a class by itself by reason of its distinguished history, its important public functions, and the notable attainments of those elected to its Fellowship which is regarded as the highest British distinction in science. Founded in 1660 or earlier, it is the oldest scientific society in Great Britain and one of the oldest in Europe. In the early years the " correspondence " which was actively maintained with continental philosophers formed an important part of the society's labours, and selections from this were the beginning of the *Philosophical Transactions* ; a publication now supplemented by the separate *Proceedings* (Series A, Mathematical and Physical ; Series B, Biological).

Throughout its history the Royal Society has often been consulted by Government on many subjects and it now exercises a variety of more permanent public functions: it provides seven of the Board of Visitors of the Royal Observatory, Greenwich; its committees co-operate with those of the Meteorological Office; its President and Council exercise scientific control over the National Physical Laboratory; it administers an annual Government grant for the promotion of scientific research other than that performed by the D.S.I.R.; and it appoints British delegates to the International Council (page 181). The number of Fellows is 450 and (since 1847) not more than 15 can be elected in any one year; candidates require the recommendation of six or more existing Fellows of whom not less than three must certify from personal knowledge. Weekly meetings are held from November to June at which papers of a high order are presented for discussion, their scope extending to all branches of physical science, with emphasis on the more fundamental aspects.[1]

(The British Academy was founded in 1904 to cater in a similar way for the non-physical sciences with which this book is not concerned.)

Election to membership of the remaining learned societies which are mentioned below is not as a rule made conditional on any particular standard of scientific attainment on the part of the candidate, but service on their governing bodies is, of course, a distinction.

The Royal Institution of Great Britain was founded in 1799 "for the promotion of science and the diffusion and extension of useful knowledge". It maintains an honorary

[1] The Royal Society is also an experimental organisation in so far as it maintains the Mond Laboratory (regarding which see *Engineering*, Vol. 155, pp. 146–7).

professorship and four other professorships in natural philosophy, chemistry, physiology and astronomy respectively, to which men of great eminence are appointed who are among the lecturers at the weekly evening meetings, "Friday evening discourses" (afterwards printed in the *Proceedings*) and courses of afternoon lectures with experimental demonstrations. There are also laboratories for experimental work but there is no general provision for the acceptance and discussion of papers. The subjects dealt with are mainly pure science, occasionally music and art. There is a library of 65,000 volumes including many of great historical interest.

The Royal Society for the Encouragement of Arts, Manufactures and Commerce (usually known as the Royal Society of Arts and not to be confused with The Royal Society above mentioned) was founded in 1764 at a time when only two of the learned societies now existing were in being, and when there were no departments of state or other institutions to deal with matters of public health, agriculture, forestry, colonies, etc., for which separate provision now exists. In all these and many other spheres the society derives—to quote from its descriptive booklet—"from its long and distinguished record full authority to serve as liaison between the various practical arts and sciences, and provides a medium for the announcement by leading authorities of recent developments of more than specialised interest. The society also exists as a potential agent for the inception of parts of public services which do not fall very definitely within the scope of any more specialised body." Papers are read and discussed and lectures are delivered on a wide range of subjects, artistic, scientific and technical; commercial and technological examinations are held; industrial art is en-

couraged by the grant to not more than 40 holders at one time of the distinction R.D.I. ("Designer for Industry of the Royal Society of Arts") and in other ways; certain scholarships and prizes are awarded, and among the studies so encouraged is that of navigation. There is a library of 10,000 volumes and a weekly *Journal* which provides a valuable medium for the publication of papers on a great variety of subjects, frequently of industrial interest and sometimes not easily placed elsewhere.

The British Association for the Advancement of Science (usually called the British Association) is a body which seeks to promote general interest in science and its applications, without normally requiring any technical qualification for admission as a member. It organises an annual meeting which extends usually over eight days in the late summer in a different town each year, at which papers are presented for discussion in the following sections:

A. Mathematical and Physical Sciences.
B. Chemistry.
C. Geology.
D. Zoology.
E. Geography.
F. Economic Science and Statistics.
G. Engineering.
H. Anthropology.
I. Physiology.
J. Psychology.
K. Botany.
L. Educational Science.
M. Agriculture.

Apart from the above a separate division of the British Association was founded in 1938 to deal with Social and International Relations of Science.

The addresses (often important) delivered by the president and the sectional presidents are published under the title of *The Advancement of Science* and a complete report of each annual meeting appears later; some of the individual papers are reprinted by the association and others appear in independent journals. The other main activity is the appoint-

ment and administration of research committees on particular subjects, of which between 60 and 70 are usually at work throughout the year; it is claimed that their recommendations have initiated many important movements for the advancement of science.

Other learned societies not limited to particular sciences are the Royal Society of Edinburgh (which publishes *Transactions* and also *Proceedings*), the Royal Dublin Society (issuing separate *Scientific* and *Economic Proceedings*) and the Royal Irish Academy, Dublin (*Proceedings:* Section A—Mathematical, Astronomical, Physical; Section B—Biological; Section C—Archæology, Linguistics and Literature).

UNSPECIALISED ENGINEERING INSTITUTIONS

The Institution of Civil Engineers, founded in 1818, was the first of its kind in the world and has served as the prototype of the many others to which the expansion of the engineering field has since given rise. It retains its premier position through being in no sense a rival of these but rather by standing to them in a relationship like that of the Royal Society to those learned societies which cultivate particular branches of science; that is to say, the weight of its interests has always tended to lie in the consideration of fundamental advances which concern engineering science generally, and in the discussion of major engineering works in which the specialised branches of the art are combined and co-ordinated. Thus the imaginary example described at the beginning of this book (pages 4–7) would, if it were real, form a typical subject for treatment in a paper before the "Civils" to deal with the work as a whole, in parallel with other papers before the "Mechanicals", the "Electricals", and other institutions on their particular interests therein.

It is important to note in this connection that the term "civil engineering", which originated in contradistinction to military engineering, can be used in at least two different senses. In its narrower usage it now covers only structural, hydraulic and similar public works to the exclusion of mechanical, electrical and other specialised branches of engineering; but the Institution of Civil Engineers has never wavered from its claim that "civil engineering" means every kind of engineering covered by the famous definition as "the art of directing the great sources of power in nature to the use and convenience of man", and therefore includes mechanical and electrical work within its scope. There may have been times in the past century when the claim of the Institution of Civil Engineers to stand for engineering as a whole has been impaired by a too exclusive policy which defeated itself in unduly stimulating the growth of new and separate institutions, but any such tendency has since been replaced by a sounder one towards co-operation and mutual recognition in the sense described above. This newer attitude found expression in the terms of the amendment, in 1936, of the Royal Charter of the Institution; in the exemption from part of its own qualifying examination granted in 1938 to members of certain other institutions and the setting up later of an Engineering Joint Examination Board; in the increasing frequency of joint meetings and activities with other institutions; in the improved collaboration of several institutions for the compiling of *Engineering Abstracts*; and in other signs.

The roll of the Institution of Civil Engineers in 1945 totals 14,701, made up of 13 Honorary Members, 2,281 full Members, 8,039 Associate Members, 38 Associates (persons of suitable standing in allied professions not eligible to become members), and 4,330 young men admitted under

the designation of Students while training for the profession.

The Institution's activities cover practically all the points enumerated here on page 141, the prestige which enables it to fulfil item (*f*) and lends weight to the counsel of its representatives on Government and other outside committees being derived largely from the importance attached to item (*e*). Admission to Associate Membership is by way of written and oral examination (from which a university degree in engineering secures partial but not complete exemption) supported both by evidence of approved practical training and experience extending over several years and by the recommendation of not less than five members, of whom three can speak of the candidate from personal knowledge. Transfer (or in certain cases direct admission) to full Membership is possible only after the age of 35 and depends on high professional attainments. Thus Associate Membership amounts to a professional qualification; full Membership is a distinction; and election to the Council is a high distinction.[1]

The Institution's most important service to engineering has always been the reception, discussion and subsequent publication of papers written by its members largely of the type mentioned on page 79. Until 1936 the medium of publication for these was the bi-annual volumes of the *Minutes of Proceedings* supplemented by *Selected Engineering Papers* published separately without discussion; since that

[1] Subject to variations of detail this paragraph applies also to the Institutions of Electrical, Mechanical, Municipal and County, and Structural Engineers and some others. These, like the Institution of Civil Engineers, also have local sections or associations of members at provincial and overseas centres where meetings for the discussion of papers are held. Corporate members of certain institutions so authorised by Royal Charter have the right to describe themselves as Chartered Civil (Electrical, Mechanical, etc.) Engineers.

date the medium has been a *Journal* which appears eight times a year.

Until 1935 research by the Institution as such, as distinct from the contributions of its members, was limited to investigations conducted by committees appointed specially in each case. Important results have been obtained in this way, including those of an investigation of long standing still in progress (the subject of no less than 17 interim reports) relating to the Deterioration of Structures of Timber, Metal and Concrete Exposed to the Action of Sea Water: the report issued in 1938 gave complete quantitative results of the 5-, 10- and 15-year experiments on the corrosion of iron and steel specimens exposed for this purpose all over the world. In 1935, however, a permanent Research Committee was set up with the duty of making recommendations to the Council on subjects for investigation and of maintaining contact with other bodies engaged in similar work, and on this basis a more active and continuous policy is now being pursued. The committee has mainly limited its activities to problems in branches of engineering not ordinarily included in the programmes of the more specialised institutions but it has actively co-operated with many of these in researches of common interest, the general headings under which the work is classed being those of Materials, Soil Mechanics, Hydraulics, Structures, and Specialised Engineering Practice. The last-mentioned includes subjects varying from the most desirable type of fish lift in rivers to the standardisation of self-contained breathing apparatus for use in sewers and other engineering works, and the drafting of regulations for the use of water mains as electrical earths.

During the war the normal lines of research have been restricted, but work under the control of the Institution

has been continued on Soil Mechanics and Thermal Expansion of Concrete at the Building Research Station, as well as on Soil Corrosion of Metals and the Earthing of Metal Water Pipes and Water Mains elsewhere.

Another development of the past few years has been that of Divisions, within the Institution, composed of members having specialised interests. Each such Division holds meetings of its own and is guided by a Divisional Board able to advise the Council on matters pertaining to its interests. The first two to be formed were those for Railway Engineering and Road Engineering, and in 1944 it was decided to set up two more Divisions, respectively for Maritime Engineering (the title of which has since been amended to cover also inland waterways) and for Works Construction. The last mentioned, which relates to matters in which civil engineering contractors are interested, held its first meeting in January, 1945, when a discussion took place on "The Organisation of Civil Engineering Work" based on a report recently published by the Institution. A further Division is under consideration to deal with Airport Engineering.

The Institution's library contains 66,543 volumes and about 17,500 pamphlets, which are available for reference by members in addition to a separate loan collection of 1,600 volumes. Arrangements now exist for the interchange of library facilities with those of the joint library of the Iron and Steel Institute and the Institute of Metals.

Two other institutions whose interests are neither local nor specialised are the Society of Engineers (founded 1854; quarterly *Journal*) and the Junior Institution of Engineers (founded 1884; monthly *Journal*). The former with some affiliated societies at various centres had in 1939 a member-

ship of 2,550 to which admission is by examination; the latter has now 1,800 and no examinations, its purpose, as suggested by its title, being the help and encouragement of the younger men; but there is nothing "junior" in the quality of the papers it publishes. Yet another such body is the Women's Engineering Society.

Ireland, Scotland and Wales have their own national societies, namely, the Institution of Civil Engineers in Ireland (1835; *Proceedings*), which is independent of the local branch of the Institution of Civil Engineers, London, with the younger but virile Belfast Association of Engineers (1892) in Northern Ireland; the Institution of Engineers and Shipbuilders in Scotland (1857; *Transactions*); the North-East Coast Institution of Engineers and Shipbuilders (1854; *Transactions*); and the South Wales Institute of Engineers (1857; *Proceedings*). In the chief manufacturing towns there are local societies such as the Manchester Association of Engineers (1856), the Liverpool Engineering Society (1875; *Transactions*), the Rugby Engineering Society (*Proceedings*) and many others.[1]

SPECIALISED ENGINEERING INSTITUTIONS

The four institutions of Civil, Mechanical and Electrical Engineers and of Naval Architects are regarded as pre-eminent.

The Institution of Mechanical Engineers, established in 1847, has now over 20,000 members organised in six grades. In its particular sphere it enjoys the same high status and performs much the same functions as "the Civils", with

[1] This paragraph and much of the next section are based on a useful paper by M. Mowat: British engineering societies and their aims. *Proc. I. Mech. E.* Vol. 137 (1937), pp. 333–44.

special attention to research,[1] the subjects already investigated including alloys, castings, cutting tools, friction, gas engines, hardness tests, marine steam and oil engine trials, refrigeration, steam nozzles and wire ropes.

There are specialised Groups for the study of Applied Mechanics, Education, Hydraulics, Internal Combustion Engines, Industrial Administration and Production Engineering, and Steam, with separate meetings for members interested in these subjects. All papers and research reports are printed in the *Proceedings* in parts accumulating to two indexed volumes annually. There is a library of 35,000 volumes and 350 periodicals, in which about a thousand searches for specialised information are made every year. Apart from its own qualifying examinations the Institution co-operates with the Ministry of Education and the corresponding authorities in Scotland and Northern Ireland in the award of National Certificates in Mechanical Engineering to successful students at many technical colleges and schools.[2]

The Institution of Electrical Engineers, founded in 1871, is the third of what are sometimes called the " big three ". Its roll—8,440 in 1920, 14,200 in 1930 and 20,250 in 1940—totalled 25,327 in 1944, of whom 2,513 were full Members and 9,654 Associate Members. Here again the most prominent work is the holding of meetings at which papers

[1] C. W. J. Taffs in *The Central*, July 1937, pp. 65–71, described how this work began and is organised, outlined the researches then in hand, and mentioned that about half of the 1,700 pages per annum of *Proceedings* were taken up with results of researches.

[2] The Institution of Civil Engineers, Institution of Electrical Engineers, Institution of Naval Architects, Institute of Builders and Institute of Chemistry also conduct schemes of National Certificates in their respective subjects ; the Royal Aeronautical Society and the Institute of British Foundrymen co-operate by endorsing these certificates where candidates have taken their special subjects. Possession of such a certificate secures exemption from part of the Associate Membership examinations of these bodies.

are presented and discussed, and within the Institution there are separate sections on Radio (formerly Wireless), Measurements (formerly Meters and Instruments) and Transmission for the reception of papers on these subjects. Papers so presented, as well as at the ordinary meetings, are published in the *Journal* which appears in three separate parts:

Part I : " General "—including all general and formal proceedings and also abstracts of the papers in Parts II and III—issued monthly.
Part II : " Power Engineering "—issued six times a year.
Part III : " Radio and Communication Engineering "—issued quarterly.

The Research Committee set up in 1912 led to the establishment of the B.E.A.I.R.A. (see page 113) in the control of which the Institution still shares. Other committees do important work in connection with standardisation—the Institution being one of the constituent bodies of the International Electro-technical Commission as well as of the British Standards Institution—and the drafting of regulations for electrical equipment. The seven technical committees under the Council deal respectively with Applications of Plant, Electricity in Mines, Electro-chemistry and Electro-metallurgy, Power Stations and their Equipment, Radiological and Electro-medical Apparatus, Telegraphs and Telephones, and Traction including railways. There is a library of 20,000 volumes and the Institution publishes *Science Abstracts (Section B)—Electrical Engineering.*

The Institution of Naval Architects (1860) is much smaller but of high standing. Its roll totals 2,577 of whom about half are full Members and one-quarter are Associate Members qualified by examination. The object pursued is " to promote the improvement of ships " including both merchant vessels and warships. The Institution is represented

on many committees including that which administers the William Froude Laboratory (page 102). Meetings for the reception of papers are not spread over the year but are concentrated in a continuous session of several days in the spring, recorded in a volume of *Transactions*.

Complementary to this, laying emphasis more on the mechanical side, is the Institute of Marine Engineers (1889) with a roll of some 4,500 (of whom three-quarters are full Members) connected with the designing, building and operating of ships. Fortnightly meetings are held and *Transactions* are published.

The Institution of Structural Engineers, founded in 1908 as the Concrete Institute, was granted a Royal Charter in 1934 " for the promotion of the Science and Art of Structural Engineering " and now has a roll of 4,428, of whom 1,275 are full Members, and 2,070 Associate Members. It is especially active in collative research through numerous Committees organised on the pyramidal system explained on page 33; that is to say, a report drafted by a small panel of experts appointed for the purpose is submitted for consideration by the Concrete, Steelwork, Masonry, Timber, Research or Foundations Sectional Committee as the case may be, and the Sectional Committee when satisfied forwards it to the Science Committee which in turn may recommend it to the Council for publication. These reports, sponsored by the Institution as such, are published separately, but papers by individual members appear in the monthly Journal, the *Structural Engineer*. The Institution has since 1943 been engaged in the drafting of Codes of Practice for reconstruction purposes in conjunction with the Ministry of Works, and as regards these acts as Convenor Institution for Load Bearing Superstructures and Earth Retaining Structures. In addition, the Institution, at the request of the Ministry of

Works, submitted a report on Reinforced Concrete Structures in the series *Post-War Building* which is mentioned on page 168.

The Royal Institute of British Architects is not, of course, an engineering institution, but should be mentioned here (with its weekly *Journal*) as the governing and qualifying body of a sister profession with which structural engineering, especially, has many contacts. In that field there is also the Architectural Association which, in addition to other activities, conducts a school of architecture.

The Institution of Municipal and County Engineers has a membership of 4,300 composed largely of technical officers of local authorities, admitted by examination : it issues a fortnightly *Journal* and is concerned in the organisation of the annual Public Works and Transport Congress and Exhibition. Its interests make contact in various directions with those of still more specialised bodies such as the Royal Sanitary Institute (fortnightly *Journal*), Royal Institute of Chartered Surveyors [1] (monthly *Journal*), Institute of Transport (monthly *Journal*), Town Planning Institute, Institute of Highway Engineers, Institution of Sanitary Engineers, Institute of Plumbers, Institute of Sewage Purification [105·1], Institute of Public Cleansing and Institution of Water Engineers.

The Institution of Mining Engineers is a federation of a number of local associations (including the North of England Institute of Mining and Mechanical Engineers dating from 1852) whose papers are published in the *Transactions*

[1] Formerly the Chartered Surveyors' Institution. Surveying is a word with many meanings, this institution being concerned largely with questions relating to property in land and building. Engineering surveying as exemplified on page 5, is among the interests of the Institution of Civil Engineers and map-making among those of the Royal Geographical Society. For surveying in the sense of the inspection of plant, ships, etc., see page 173.

of the central body. The Institute of Mining and Metallurgy is a separate society, as are the Institution of Petroleum Technologists (monthly *Journal*), the Institute of Fuel (*Journal* six times a year) and the Institute of Quarrying.

Other institutions dealing with special branches of engineering include—

Air Raid Protection Institute (monthly *Journal*).
British Association of Refrigeration (*Proceedings*).
British Compressed Air Society.
British Institution of Radio Engineers.
Illuminating Engineering Society (monthly *Transactions*).
Institute of Welding, Ltd. (*The Welding Industry* monthly).
Institute of Wireless Technology, Inc. (monthly *Journal*).
Institution of Fire Engineers (annual *Report and Proceedings*).
Institution of Heating and Ventilating Engineers (monthly *Journal*).
Institution of Locomotive Engineers (*Transactions*).
Permanent Way Institute (*Transactions*).
Royal Aeronautical Society (monthly *Journal*).

to which may be added the following examples of associations of users, as distinct from constructors, of engineering plant :

Coke Oven Managers' Association (*Year Book* containing *Transactions*).
Diesel Engine Users' Association.
Institute of Road Transport Engineers, Ltd.
Institution of Engineers-in-Charge.
Tractor Users' Association.

The Newcomen Society (1920) is for the study of engineering history. The Smeatonian Society was a forerunner of the Institution of Civil Engineers which survives only as a dining-club for senior members of the latter.

CO-ORDINATION OF ENGINEERING INSTITUTIONS

Altogether there are in Great Britain over a hundred engineering institutions of all kinds having an aggregate

membership of more than 100,000. It is thought by some that too many separate societies exist; but differences in outlook and in the standards of qualification for membership make it unlikely that any proposal to merge or federate them will become practical politics at present. There is, however, increasing co-operation in several ways. Joint meetings are frequently arranged, and also technical conferences (sometimes international in scope) lasting several days in the organisation of which many institutions share—for instance, on Welding in 1936 and on Lubrication in 1937. The Joint Committee on Materials and their Testing (centred at the Institution of Mechanical Engineers) is a permanent organisation of the same kind. A unified index of publications would be invaluable but this has not yet been brought about.

The Engineering Public Relations Committee, set up at the end of 1936 by representatives of 14 principal engineering institutions, exists for the purpose of disseminating knowledge of the general advancement of engineering science by means of lectures before public audiences and in schools, co-operation with the press and the British Broadcasting Corporation and other suitable means.

The Engineering Joint Council established in 1922 consists of representatives of four founder and four co-opted institutions who consider matters affecting the profession generally.

SOCIETIES CONCERNED WITH CHEMISTRY, PHYSICS AND METALLURGY

In regard to chemistry[1] it may be said, speaking quite loosely, that the first four functions enumerated on page 141 are looked after by the Chemical Society and the Society

[1] The handbook cited at [93·2] devotes 36 pages to particulars of 39 societies directly or indirectly connected with chemistry.

of Chemical Industry and the second four by the Royal Institute of Chemistry.

The Chemical Society was founded in 1841 and is the oldest of its kind in the world. Its main functions are to foster original research in chemistry and to facilitate the discussion and dissemination of new knowledge in all branches of science. It had a membership at the end of 1944 of 5,885 Fellows. Scientific meetings are held twice monthly from October to June in London and at frequent intervals outside London, at which lectures are given, and papers embodying the results of research are read and discussed. The Society maintains a Reference and Lending Library of 46,000 volumes, which is open to Fellows and to members of nine other bodies. Its Research Fund is available for the assistance of research, and sums amounting to some £700 are granted annually. Besides its monthly *Journal*, containing results of investigations in the whole field of Pure Chemistry, it publishes an *Annual Report on the Progress of Chemistry*, and it also collaborates with the Society of Chemical Industry, the Physiological Society, the Biochemical Society and the Anatomical Society in publishing the monthly *British Chemical and Physiological Abstracts*, which are divided into three sections : A.I—General, Physical and Inorganic Chemistry ; A.II—Organic Chemistry ; A.III—Physiology and Biochemistry.

The Society of Chemical Industry was founded in 1881 " to advance applied chemistry and chemical engineering in all branches " ; it has about 4,000 members and publishes a weekly journal *Chemistry and Industry* in addition to *British Chemical Abstracts—Section B*, and an annual *Report on the Progress of Applied Chemistry*. The society as such holds an annual meeting of a week's duration at different centres from year to year ; in addition, separate monthly meetings are

arranged by 18 local sections and also many meetings by the (non-territorial) groups of the society concerned respectively with Chemical Engineering, Food, Plastics, Road and Building Materials. Frequently these are joint meetings with other scientific organisations.

The Royal Institute of Chemistry was founded in 1877 and incorporated by Royal Charter in 1885, but the title of "Royal" is a recent addition. It now has a roll of 9,474, comprising 3,169 Fellows and 6,305 Associates. Its principal aims are those we have symbolised by (*e*) and (*g*) on page 141, but it is also active in regard to (*d*), (*f*) and (*h*). With a view to elevating the profession of chemistry, strict rulės are imposed, and Associates are admitted only after passing an examination in general chemistry unless they hold a good honours degree from a British university with chemistry as the principal subject. Fellows have to pass a higher examination in some special branch of the science. The *Journal and Proceedings* appears six times a year.

The Chemical Council, formed in 1935, consists of three members nominated by each of the aforementioned three societies, others representing the Faraday Society (see below), and three representatives of industry co-opted by the other members through the Association of British Chemical Manufacturers. The Chemical Council administers a fund which makes grants to the constituent bodies for publications, library facilities, the promotion of research and the provision and equipment of suitable buildings. A scheme of co-operation exists whereby members of the constituent bodies can become Joint Members of all three at reduced annual subscriptions.

The Institution of Gas Engineers "to promote engineering science as applied to the gas industry" dates from 1863

and has now some 1,650 members; its main functions are (*a*), (*b*), (*d*) and (*e*) and it publishes *Transactions* yearly and *Communications* twice yearly.

The Institution of Chemical Engineers was founded in 1922 to act as a professional and qualifying body in reference to the wider scope indicated by its title.

The Institute of Physics was founded in 1918 for the elevation of the profession of the physicist and the advancement of both pure and applied physics—objects which it pursues by making an honours degree in physics followed by professional experience the normal condition for admission to its Associateship and by requiring still higher attainments for Fellowship, and by co-ordinating the work of the Physical Society (see below), Royal Meteorological Society, British Institute of Radiology and Faraday Society. The last mentioned is concerned with the publication of new knowledge relating to physical chemistry, and forms a link between the various bodies interested in physics and those interested in chemistry. Each of the above-mentioned maintains its own activities and publications.

Under the title *Progress in Physics* the Physical Society publishes a comprehensive annual review, by leading physicists, of recent work in general and atomic physics. The same society, jointly with the Institution of Electrical Engineers and certain American and (until the war) Italian bodies, produces *Science Abstracts (Section A)—Physics.* It holds an annual exhibition of scientific instruments, the *Catalogue* of which describes several hundreds of these under the names of the exhibitors. The Institute of Physics, as such, occasionally holds a small exhibition of this kind in connection with its conferences on industrial physics (normally in the provinces) and publishes the monthly *Journal of Scientific Instruments.*

There is also a Royal Physical Society of Edinburgh which publishes *Proceedings*.

Ferrous and non-ferrous metallurgy are the concern respectively of the Iron and Steel Institute [1] (*Journal* twice a year) and Institute of Metals (*Journal* six times a year) which work closely together and share the same library. In September 1945 a new Institution of Metallurgists was formed which, supplementing but not superseding these existing societies, will " bring within one professional body qualified metallurgists engaged in production, research, teaching, consulting work, inspection or any other metallurgical activities associated with any branch of industry ". There are also the Institute of British Foundrymen, Manchester (*Proceedings*) and the Sheffield Metallurgical Association.

Other bodies, most of which concentrate on purposes (*a*), (*b*) and (*c*) as listed on page 141, include the following:

Association for Scientific Photography.
British Colour Council.
British Kinematograph Society (*Journal*).
Electrodepositors' Technical Society (*Journal*).
Institute of Brewing (monthly *Journal*).
Institute of the Plastics Industry (*Transactions*).
Institution of Electronics.
Institution of the Rubber Industry (bi-monthly *Transactions*).
Institute of Vitreous Enamellers.
Oil and Colour Chemists' Association (monthly *Journal*).

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[1] A 20-page handbook of *Notes on the Work and Activities of the Institute* was published by it in 1939. For a description of the whole field, explaining the organisation of the work carried on jointly by this institute, the British Iron and Steel Federation and the D.S.I.R. (many other bodies co-operating), and also the organisation of the Brown-Firth Research Laboratories at Sheffield which that author directs, see W. H. Hatfield: *Research in the Iron and Steel Industry* (10th Gluckstein Memorial Lecture, Institute of Chemistry, 1938).

Royal Photographic Society (monthly *Journal*).
Society of Dyers and Colourists, Bradford (monthly *Journal*).
Society of Glass Technology, Sheffield (bi-monthly *Journal*).
Society of Public Analysts and other Analytical Chemists (*The Analyst* monthly).
Society of Radiographers.
Television Society (*Journal*).

STANDARDISING ORGANISATIONS

The purpose of standards has already been discussed on page 63. Their formulation provides an important example of collative research drawing upon the experience of all the parties concerned. As regards national standards in this country it is carried out by the British Standards Institution, a body which originated in 1901 as a single committee of eight members and by 1939 had grown to a vast pyramidal organisation as follows :

General Council

Building Divisional Council	Chemical Divisional Council	Engineering Divisional Council
2 industry committees.	5 industry committees.	15 industry committees.
58 technical committees.	41 technical committees.	270 technical committees.
63 sub-committees.	69 sub-committees.	343 sub-committees.
10 panels.	36 panels.	107 panels.

These figures are from the 1939 edition of the *Handbook* of the Institution, since when the growing interest in and need for standardisation has further widened its scope and activities. The *British Standards Yearbook*, 1944–5, consequently shows 7 instead of 2 industry committees under the Building Divisional Council, and 14 instead of 5 under the Chemical Divisional Council ; it does not give detail of the lower committees but shows the total membership

of all committees as 9,500 as against 4,500 before the war, and the number of meetings held as nearly 25 per cent. greater (though in 1940 there was an understandable drop).

Membership of the Institution is open to all British subjects and companies, technical and trade associations, local and public authorities. Its divisional councils and industry committees include representatives of all relevant associations, the Department of Scientific and Industrial Research, and other Government departments. The 9,500 members of the many hundreds of committees mentioned above are engineers, chemists, architects and other professional men throughout the country who freely give their time and experience in attending the meetings for the purpose of contributing to and criticising the drafts of proposed specifications. When the committee members numbered 4,500, the value of these voluntary services was estimated at £40,000 per year in addition to an actual expenditure of about £25,000 met by contributions from industry and by a Government contribution of £3,000.

The specifications, after being circulated in draft form for comment and being finally approved by the General Council, are published by the Institution as *British Standard Specifications*, of which 1,325 are now available, and the number of copies distributed is fast approaching four millions.

The 1939 edition of the *Handbook*[1] of the Institution contains lists and indexes of all British Standard Specifications and also of Government Department Co-ordinated Specifications for General Stores, Textiles and Clothing. Particulars are included of the 25 national standardising organisations in the overseas Empire and foreign countries

[1] For a useful general account see also J. F. Stanley: Standardisation and the work of the British Standards Institution. *Proc. Br. Soc. Intl. Bibliog.*, 22 Jan. 1941, pp. 57–67.

with which the Institution maintains contact and whose specifications it keeps on file. The following quotation from this source may be of interest:

> The British Standard Specifications are based on what is best in present practice, and do not attempt to attain an ideal which might be too costly to adopt, providing a generally suitable standard of performance, quality or dimension, and an equitable basis for tendering. They help to eliminate redundant qualities and sizes and enable manufacturers to provide stock during slack periods and purchasers to obtain their requirements more rapidly. The Specifications are kept up to date by periodic review and, when necessary, revision; they do not interfere with individual initiative and invention and they leave the producer as much freedom as possible in his methods of production. The Specifications are, as far as possible, confined to questions of performance.
>
> The underlying principles covering the preparation of the British Standard Specifications are that: they shall be in accordance with the needs of industry and fulfil a generally recognised want; the community interest of producer and consumer shall be maintained through the work; periodical review and revision shall be undertaken to prevent crystallisation and keep the work abreast of progress; there shall be no coercion whatever by one section of the community over another section, the standardisation being arrived at by general consent.
>
> The *British Standards Yearbook* serves as a catalogue with a brief descriptive note on each specification.

In 1944 the Institution began issuing from time to time a *Standards Review* containing notes on its work. No. 5 of this publication of 32 pages, dated January 1946, refers to the fact that industries not previously familiar with its procedure have been brought into contact with it through the wartime action of H.M. Government in imposing many of the British Standard Specifications as part of the organisation of the national economy: "it is desired, therefore, to emphasise . . . that with the cessation of the necessity for

war standards no British Standard will be issued or promulgated without the general approval of those concerned. . . . An Industry Committee set up by the B.S.I. has practically complete autonomy." Varied instances of the widening scope of the Institution's interests include Quality Control (see page 28), documentation,[1] and a British Standard now in preparation to give a limiting cleanliness-figure and detailed cleaning instructions applicable to filling materials for upholstery and bedding, etc., as a basis for improvement in the law; for at present " there is nothing to prevent the use of feathers, hair or other materials which are in a filthy or even verminous condition. Feathers can be taken from a fifty-year-old feather bed or straight from a poultry yard and put into a feather pillow for baby."

In many fields international standardisation is clearly desirable—imagine, for instance, the chaos that would exist if the definitions of the electrical units of measurement or the gauges of cinema films varied from country to country, as unfortunately do screw threads between British and American practice as pointed out on page 64. So important was this last matter found to be under war conditions that in 1944 a joint United States-Canadian Screw Thread Mission visited this country to discuss it, which led to a conference on the Unification of Engineering Standards being held at Ottawa in the autumn of 1945 under the auspices of the Combined Production and Resources Board. The report on this conference, released in March 1946 by the Ministry of Supply and of Aircraft Production, records agreed recommendations on a very wide range of standardisation subjects

[1] B.S. 1000 embodies parts of the Universal Decimal Classification: see page 242. B.S. 1153 is "Recommendations for the storage of microfilms". B.S. 1219 is "Printers' and authors' proof corrections". Other standards are in preparation for the alphabetical arrangement of indexes, etc., and for the quotation of bibliographical references.

such as screw threads, limits and fits in engineering and drawing office practice. The British Standards Institution has been invited to give these recommendations early consideration in consultation with the industries affected.

Apart from this, a United Nations Standards Co-ordinating Committee formed in 1943 met in New York late in 1945 to draft a constitution for a permanent international body to continue the work it had begun as a war measure. Fifteen nations were represented.

Before the war, an International Standards Association with headquarters at Basle had been formed in 1926 and the British Standards Institution joined in its work from January 1938. The feeling at that time was that such efforts were evidently desirable, but should be pursued with circumspection, lest international standardisation be used as a stalking-horse for the advancement of goods manufactured to lower standards than those adopted by countries which have already gained and are anxious to defend their goodwill in international markets. In considering this matter it will, perhaps, assist clear thinking if a distinction be drawn between what are really separate issues: the standardisation respectively of terminology, of units of measurement, of dimensions of parts which need to be interchangeable, of methods of testing, and of the quality of manufactured products.

In the electrical industry international standardisation is already to some extent attained, it being found, to an increasing extent, that purchasers of electrical machinery prefer to ask for tenders to be submitted in accordance with the recommendations of the International Electrotechnical Commission (a body which has been in existence since 1906) rather than with the British, German, American or other national standards.

PARLIAMENTARY AND SCIENTIFIC COMMITTEE

In November 1939 the Parliamentary and Scientific Committee took over the functions of the Parliamentary Science Committee, which had suspended its activities on the outbreak of hostilities.

The Parliamentary and Scientific Committee is a non-party body formed with the object of providing a permanent liaison between scientific bodies and Parliament. The Committee endeavours to enlist the interest and support of as many scientific societies as possible, so that the influence of science can be effectively felt in the councils of the State.

The Committee strives amongst other things to provide Members of Parliament with authoritative scientific information in connection with debates; to bring to the notice of Members of Parliament and Government departments the results of scientific research and technical development which bear upon questions of current public interest; to arrange for suitable action through Parliamentary channels whenever necessary to ensure that proper regard is had for the scientific point of view; to examine all legislation likely to affect the foregoing and to take such action as may be suitable; to watch the financing of scientific research; and to provide its members and other approved subscribers with a regular summary of scientific matters dealt with in Parliament. This information appears in a quarterly journal, *Science in Parliament.*

During the war the Committee also issued *Coal Utilisation Research in Great Britain*, *Scientific Research and the Universities in Post-War Britain*, and *District Heating*. Subjects dealt with in its earlier work include the remission of income tax expended on research, the Fire Brigades Act and a projected barrage across the Thames.

GOVERNMENT DEPARTMENTS

The Admiralty, War Office and Air Ministry control establishments at which experimental as well as collative scientific work is done and have, therefore, already been mentioned in the preceding chapter at page 121 ; the same applies to the General Post Office at page 129.

Apart from these there are many of the civil ministries which have departments, branches or inspectors fulfilling technical responsibilities in various directions, whose reports and other publications (obtainable through H.M. Stationery Office as listed in [202·1]) often are of value as authoritative sources of information. For instance, the Home Office is concerned with accident prevention and its Reports of the Inspectors of Factories are of interest in this connection ; it also maintains a Museum relating thereto in Horseferry Road, London, S.W.1. Similarly—to give merely a few random examples—the Ministry of Health issues Reports of Inspectors of Alkali, etc., Works ; the Board of Trade, reports of Examiners under the Gas Undertakings Act ; the Ministry of Transport, reports of Inspectors of Railway Accidents ; the Mines Department, various reports, and its associated Safety in Mines Research Board, a *Monthly Bibliography of Current Periodical Literature* bearing on this subject.

The new Ministries set up during the war are active in technical documentation in various directions. The Ministry of Fuel and Power is responsible for a series of Fuel Economy Handbooks and for a monthly broadsheet, *Fuel Economy News*. The Ministry of Home Security has been issuing to government departments and certain other addressees a series of technical abstracts (type C.5 in terms of the table on page 205) relating to building matters as affected by fire

and similar risks from enemy action. Much of the knowledge it has accumulated on these and similar subjects should be of permanent value and will no doubt be inherited by the new Ministry of Works. The latter is itself sponsoring work by the Codes of Practice Committee for Civil Engineering, Public Works and Buildings, which has been formed at the British Standards Institution and has already issued two such *Codes of Practice*. The Ministry of Works, in collaboration with the Royal Institute of British Architects and the engineering institutions and other expert bodies respectively interested, is also bringing out a useful series of handbooks relating to house and other building construction and equipment entitled *Post-War Building*. Similarly, the Ministry of Town and Country Planning is issuing many reports bearing on its fields of interest.

The Ministry of Food has an Infestation Division which co-operates with the Ministries of Agriculture and Fisheries, and of Health, on the control of rats, mice, insects, mites, moulds, etc. Similarly its Dehydration Division co-operates with the D.S.I.R. and others ; in 1942 it undertook responsibility for the development of this technique as applied to foodstuffs, the importance of which, especially under war and emergency conditions, may be gauged from the fact that 100 tons of cabbage occupy 15,460 cu. ft. in their normal state, but only 2,440 cu. ft. when dehydrated.

Three Scottish public bodies may here be mentioned. The Scottish Council on Industry was set up in 1942 to advise the Secretary of State for Scotland on questions relating to, or deriving from, the location of industry in that country. Supported by this and by the Ministry of Supply and the Scottish Agricultural Organisation Society there was formed, in 1944, a Scottish Seaweed Research Association. Under the Electric Development (Scotland) Act, 1943, there

has been established a North of Scotland Hydro-Electric Board to initiate and undertake such development, supply electricity in districts not already covered, and promote associated economic and social improvements such as fisheries and amenities. Several of the Board's approved *Constructional Schemes* have been published.

ORGANISATIONS CONCERNED WITH DEVELOPMENT

Investigations to furnish a basis for schemes of development are conducted normally by special staffs within the organisations concerned, or by consultants or commissions appointed to report on a particular project. As outlined on page 71, such work involves the collation of technological with economic, commercial, statistical and other knowledge extending beyond the scope of this book and the data have to be gathered largely from unpublished records or through private contacts supplemented by what can be gleaned from official publications.

An Industrial Development Commission with power to advance money for the promotion of new industries, after due investigation, has been proposed. Within existing industries the need for new factories is already largely met under the Special Areas (Amendment) Act of 1937 by such bodies as the Nuffield Trust, but the establishment of an entirely new product or of a novel process is another matter.[1]

The few companies which have been formed specially to deal with new inventions do not appear to have had any great measure of success; the necessary link between invention and finance has

[1] The following quotations are from a leading article in *Nature*, 15 May 1939, pp. 777–8, on the subject of the *P.E.P. Report* (see below) on the *Location of Industry*, 1939.

> not yet been forged. One of the major difficulties is the aggregate cost of "vetting" new propositions, which frequently exceeds the profits to be anticipated on the small proportion of successful ones. The high cost is due to the difficulty of finding any firm or organisation capable of dealing with the wide range of industries with which a concern attempting to finance new processes is usually brought into contact. . . . In November 1935 the Chancellor of the Exchequer made . . . the Department of Scientific and Industrial Research, the Medical Research Council and the Agricultural Research Council at the disposal of the banks, issuing houses and brokers to furnish them with reports on the scientific merits of the methods or substances for development of which it might be proposed to make a public issue

—but, as regards these organisations—

> it is at least open to doubt whether they possess invariably the necessary combination of commercial and technical outlook. The nature of their responsibilities limits them to making a complete and exhaustive report on a technical subject. What is often required, however, is a quick opinion based on sound judgment and wide knowledge as a basis for a decision whether to proceed with further investigation or to reject the project at an early stage.

The School of Planning and Research for Regional Development in London prepares men and women who already hold a qualification in engineering, architecture, transport, etc., to occupy posts demanding ability to co-ordinate the work of the wide range of specialised professions which have to be drawn upon and combined when producing a balanced scheme. It originated in the concern of architects with town planning, but its scope extends far beyond this, including in fact everything that is implied by the title (originally "National" instead of "Regional"). Before the war three-year courses of exercises guided by lectures from experts in many different lines of activity were conducted at hours which enabled them to be combined with

professional employment, and a Diploma was granted on completion. At present (1945) a correspondence course is provided, at the invitation of the War Office, for over a thousand members of the Forces, in which connection some useful *Broadsheets* have been produced. The daytime and evening courses will shortly be resumed.

Political and Economic Planning ("P.E.P.") also calls for mention as the name of a voluntary society, unconnected with any political party and eschewing personal publicity for its members, which carries out objective studies and publishes admirable reports from time to time as well as a monthly *Broadsheet* describing the organisation, trends, statistics and outstanding problems of industries and other economic activities of national importance.

The Federation of British Industries, through its newly appointed Industrial Research Committee, is planning to take an important part in the co-ordination and encouragement of research. A survey is being made of existing facilities ; lectures and addresses will be arranged and, where appropriate, articles written by members of the Committee ; and a conference on Industry and Research was held in March 1946.

The *Register of British Manufacturers* published annually by the Federation of British Industries gave, in the 1939 edition, besides the names and addresses of firms classified in accordance with their products and services under more than 5,000 different headings, those of 176 " trade associations ", sometimes with the names of their member firms. Many of these associations exist for the purpose of promoting the development of particular materials or groups of products not merely by advertising in the ordinary commercial sense but by reasoned advocacy appealing to scientific data which they collate and publish, often employing or consulting men

of high scientific attainments for the purpose. Such data, and the readiness of the associations to furnish them to enquirers, can often be extremely valuable to the latter, it being merely necessary to remember that where the associations in question compete against one another they are valuable not as judges but as advocates.

The following are examples of trade development associations of this kind :

Aluminium Development Association.
Asphalt Roads Association Ltd.
British Acetylene Association.
British Commercial Gas Association.
British Constructional Steelwork Association.
British Electrical Development Association.
British Granite and Whinstone Federation.
British Paving Brick Association.
British Road Tar Association.
British Slag Macadam Federation.
British Steelwork Association.
British Wood Preserving Association.
Building Centre (with permanent exhibition).
Cast Concrete Products Association Ltd.
Cement and Concrete Association.
Clay Products Technical Bureau.
Copper Development Association.
Electric Lamp Manufacturers' Association of Great Britain Ltd. (with permanent exhibition) (page 24).
Iodine Educational Bureau.
Lead Development Council.
National Association of Roofing Tile Manufacturers.
National Sulphuric Acid Association Ltd.
Reinforced Concrete Association.
Road Emulsions and Cold Bituminous Roads Association.
Rope, Twine and Net Manufacturers' Association.
Society of British Aircraft Constructors Ltd.
Society of British Gas Industries.

Society of Motor Manufacturers and Traders Ltd.
Timber Development Association.
Zinc Development Association Ltd.

As an example of the kind of work which these associations do, the British Road Tar Association have given much attention to the alleged poisoning of fish in streams which receive drainage from tarred roads and as the result of research conducted under their auspices a grade of tar ("Brotox") has been patented which is claimed to be harmless in this respect. To give two further examples, the National Sulphuric Acid Association have brought out a pamphlet on *Weed Destruction in Cornfields by Sulphuric Acid Spraying*, and the Rope, Twine and Net Manufacturers' Association a Schedule and Code of Practice on *Lifting Tackle.*

CLASSIFICATION SOCIETIES AND INSURANCE COMPANIES

The publications of officials concerned in the survey and classification of ships, boilers and other mechanical and electrical plant with a view to its insurance provide valuable data on performance in relation to design.

These surveyors enjoy opportunities denied to any other kind of engineer for collecting data on the effects of service conditions. The most conspicuous example of the use that can be made of these opportunities is that provided by the Classification Societies, of which the largest is Lloyd's Register of Shipping. The latter has normally some 500 duly qualified surveyors, stationed at the principal ports at home and abroad or in attendance at plants producing steel for shipbuilding, who have the duty of checking compliance with the detailed rules laid down by the society to govern

every aspect of the design and construction of ships and their machinery. This is done for the purpose of " classification " of the ships as regards sea-worthiness (normally that represented by the well-known symbol A 1 which is held by nearly one-half of the world's total tonnage of merchant shipping) which determines the conditions under which underwriters are willing to insure the ships. The point to notice here is that the accumulated experience of these officers fructifies in important contributions to progress in shipbuilding and marine engineering, both in the records which the society utilises for its own particular work and in the papers which they, as individuals, contribute to scientific institutions.

In other branches of engineering, data of a kind comparable with the above are sometimes available through companies concerned in the insurance of plant and equipment. To give an illustrative example, the *Technical Report* published by the British Engine, Boiler and Electrical Insurance Company for 1937 contained illustrated notes on various failures and their causes and also an original paper on " The interpretation of notched bar tests ".

COLLATION OF KNOWLEDGE FROM PRACTICAL EXPERIENCE

The application of technical knowledge to actual practice shows up its strong and weak points as no amount of forethought and laboratory experiment can do. Indeed, technical advance depends upon the maintenance of a constant interplay and mutual stimulus between Practice which asks questions of Research, Research which suggests promising but untried answers thereto, Practice again which tries them out and re-starts the cycle with further questions. It follows that no kind of collative activity is more valuable than that

which gathers its material from the field of practical applications on actual works; and this value increases with the range of the experience in both space and time.

The present chapter may, therefore, fittingly conclude with a recapitulation of the kinds of publications already mentioned in the preceding pages which subserve this end, and are to be found either as separate reports or in the columns of technical journals as discussed in Chapter Six:

(1) Papers presented before engineering and other technical institutions which have the character outlined on page 79.

(2) Data from organisations concerned with management, page 136.

(3) Records of organisations which devote themselves especially to the operating side of engineering such as, among those mentioned on the lower half of page 155.

(4) Information from trade development associations as discussed on pages 171–3.

(5) Data from Classification Societies and Insurance Companies as explained on page 173.

(6) Publications of Government departments, local authorities, and public utilities as suggested on page 167.

CHAPTER FIVE

INTERNATIONAL, IMPERIAL AND FOREIGN ORGANISATIONS

INTRODUCTION

SCIENCE is a world-wide growth. Its growing shoots normally can be transplanted from one country to another, and its fruits may advantageously be blended with those of local cultivation. To help in this there existed before the war a complex of valuable international organisations which served to cross-fertilise what would otherwise have tended to be separate and unrelated national systems of research and technical practice entailing very costly waste of effort.

Owing to the war most of these organisations are dormant if not dead; but as they will undoubtedly have to be revived, or others be set up on the same lines, the ways in which they worked are worthy of study, and moreover, their pre-war publications are still of value for reference. The notes on international organisations which were included in the original edition of this book have, therefore, been repeated below substantially as they first appeared, and for convenience the present tense has been retained as if they were still functioning normally.

Apart from these international conference-holding bodies, the British experimental and collative organisations described in the last two chapters have their counterparts (*mutatis mutandis*) in the majority of civilised countries, and to avoid needless and wasteful duplication of scientific and technical work it is of the first importance to realise that the principal

publications from abroad—amounting in the aggregate to many times the output of this country—are accessible in British libraries and are covered by abstracts in the English language. With this object, brief outlines of the scientific institutions of the British Empire in general and of India in greater detail, as of the United States and of the Soviet Union, follow below. Descriptions of other countries must wait until the post-war scientific world has had time to take more definite shape.

Foreign publications are included with the British in the purview of Chapter Six, and the language question is dealt with in Chapter Nine. Before the war there were two international yearbooks of scientific institutions : the *Index Generalis* (Paris : Masson et Cie), which appeared in both a French and an English edition, and the even more voluminous *Minerva Jahrbuch der Gelehrten Welt* (Berlin : de Gruyter & Co.). As regards the British Empire see also [93·1] and [93·2].

WORLD POWER CONFERENCE

The World Power Conference, which has its headquarters in London and national committees in about 45 countries, is concerned with the technical in relation to the statistical and economic aspects of every kind of power development. It provides for the accumulation, exchange and comparison of data on the potential resources of each country in hydro-electric power, coal, oil and other fuels and minerals and, arising out of this, data regarding experiences in the development of scientific agriculture, irrigation and transport by land, air and water—but not in such a way as to duplicate the activities of other international organisations. Its publications[1] included a monthly *Power and Fuel Bulletin* contain-

[1] In 1940, when the emergency work of the Central Office was transferred to Arnhem, it was stated that orders for *Technical Data on Fuel* should be

ing abstracts of the relevant literature, a *Statistical Year Book*, *Technical Data on Fuel* (Fourth Edition, 1937), and *Transactions* of the international conferences lasting several days each, at which papers contributed by authors of various nationalities were presented for discussion, on the lines here described on page 36, before audiences of several hundred delegates and private members from all over the world. The scope of these conferences is indicated by the following complete list of those held to date:

First Plenary World Power Conference, London, 1924.
Sectional Meeting on Water Power Development and Inland Navigation, Basle, 1926.
Sectional Meeting on Fuel Problems, London, 1928.
Sectional Meeting on Complete Utilisation of Water, Barcelona, 1929.
Sectional Meeting on Development of Sources of Energy, Tokyo, 1929.
Second Plenary World Power Conference, Berlin, 1930.
Sectional Meeting on Energy Supply for Large-scale Industry and Transport, with sessions at Copenhagen, Stockholm and Oslo, 1933.
Sectional Meeting on Chemical Engineering, London, 1936.
Third Plenary World Power Conference, Washington, 1936.
Sectional Meeting on the Supply of Energy for Agriculture, Small-scale Industries, Household Purposes, Public Lighting and Electric Railways, Vienna, 1938.

The International Commission on Large Dams is a subsection of the World Power Conference which in addition to interim investigations has held separate meetings in Stockholm, 1933, and Washington, 1936.

addressed to Mr. M. W. Burt of the Society of British Gas Industries, orders for any of the *Transactions* to Percy Lund, Humphries & Co., Ltd., The Country Press, Bradford; orders for any other publications should continue to be sent to the former offices of the British National Committee at 36, Kingsway, London, W.C.2.

OTHER INTERNATIONAL ORGANISATIONS

The World Power Conference may be taken as typical of a considerable number of international organisations of varying importance which, until the war, pursued their several objects mainly by the holding of periodical conferences in the various member countries in rotation, and afterwards publishing the proceedings. In many cases they also issue interim publications, and these include several of the series of abstracts and bibliographical notes mentioned in Chapter Six. A few hundred words of information about each of these bodies, describing their objects, membership, activities and dates of previous meetings, were to be found in the League of Nations *Handbook of International Organisations* (Geneva, 1938), from which the following list has been abstracted (leaving the addresses as given in 1938) :

International Academy on the History of Sciences (12 Rue Colbert Paris 2*e*). Congresses every 3 years.

International Association for Bridge and Structural Engineering (E. T. H., Zurich). Congresses every 4 years.

International Association for the Testing of Materials (E. T. H., Zurich). Every 3 or 4 years.

International Bureau for Physico-Chemical Standards (University, Brussels).

International Bureau for the Standardisation of Artificial Fibres (Bäumleingasse 22, Basle).

International Bureau of Automobile Standardisation (3 Avenue Friedland, Paris 8*e*). International congress once or twice a year.

International Commission on Illumination (c/o N. P. L., Teddington). Meetings every 3 or 4 years.

International Committee for the Publication of Annual Tables of Chemical, Physical, Biological and Technological Constants (Paris, with National Committees in each country).

International Committee on Light (Lausanne).

International Conference of the Principal High-Tension Electrical Systems (54 Avenue Marceau, Paris). Every 2 years.

International Electro-Technical Commission (28 Victoria Street, London, S.W.1).

International Federation of the Phonographic Industry (Hayes, Middx.).

International Gas Union (21 Rue Blanche, Paris 9*e*). Every 3 years.

International Geological Congress (address in the country organising the next session ; given as Bolchaya Ordynka 32, Moscow 17). Congresses every 3 years followed by excursions in the country where held.

International Institute of Refrigeration (9 Avenue Carnot, Paris). General conference every 4 years.

International Oil Union (70 Gersthoferstrasse, Vienna 18).

International Railway Congress Association (231 Rue Royale, Brussels). Every 3 or 4 years.

International Technical Committee on Fire Prevention and Extinction (28 Rue de Dunkerque, Paris 10*e*).

International Technical Committee on Masonry, Reinforced Concrete and Foundation Work in Modern Building (3 Rue de Lutèce, Paris).

International Tin Research and Development Council (378 Strand, London, W.C.2).

International Union of Geodesy and Geophysics.

International Union of Producers and Distributors of Electric Power (26 Rue de la Baume, Paris 8*e*). Every 2 years.

International Union of Pure and Applied Physics (45 Rue d'Ulm, Paris 5*e*). Assemblies every few years.

International Union of Tramways, Light Railways and Motor Omnibuses (18 Avenue de la Toison d'Or, Brussels). Every 2 years.

Permanent International Association of Road Congresses (203 Boulevard St. Germain, Paris 7*e*). Every 4 years.

Permanent International Association of Navigation Congresses (38 Rue de Louvain, Brussels). Every 4 years.

Permanent International Commission on Acetylene and Autogenous Welding (32 Boulevard de la Chapelle, Paris 18*e*). Congress every 2–4 years.

Permanent International Committee on Carbon Fuel (1 Place du Théâtre Français, Paris 1*e*). About every year.

The International Council serves to co-ordinate a large number of international scientific unions on specific subjects which its predecessor, the International Research Council, helped to create in the interval between the two world wars (see *Nature*, 26 Jan. 1946, pp. 56–8). Its General Assembly, due to meet every three years, did so in London in July 1946 and its relations with the United Nations Scientific and Cultural Organisation (commonly known as Unesco) are being worked out.

IMPERIAL INSTITUTE AND THE EMPIRE GENERALLY

The Imperial Institute, founded in 1893 and since 1925 under the control of the Department of Overseas Trade, is organised to assist the commercial and industrial development of the Empire. It pursues this object chiefly by collecting and disseminating information as to the resources, supplies, treatment and consumption, etc., of raw materials, by conducting laboratory investigations on raw materials and new products, and by advising on their use. It maintains at South Kensington a scientific staff with suitable laboratories, work-rooms, exhibition galleries, a cinematograph theatre and also the Empire Film Library from which films illustrating industry and agriculture at home and abroad are lent free of charge to schools and other approved bodies. The Imperial Institute has three departments—Plant and Animal Products, Mineral Resources (which publishes a *Statistical Summary of the Mineral Industry of the British Empire and Foreign Countries*), and Rubber—each with an Advisory Council responsible to the Board of Governors, on which are representatives of the Dominions, India, home Government departments and scientific and commercial interests. The library receives over 800 technical and scien-

tific journals and publishes a quarterly *Bulletin* in addition to monographs on special products and investigations.

A symposium on the Empire Contribution to the Flow of World Information held by ASLIB (see page 219) in 1944 and published in its *Report* in 1945 (pp. 21–50), includes notes on such central organisations as the Imperial Institute, Imperial Agricultural Bureaux, Bureau of Hygiene and Tropical Diseases and Royal Empire Society as well as on the bibliographical aspects of researches conducted in, or relating to, Canada, Australia, New Zealand and South Africa. These were further adumbrated at the Royal Society's Empire Science Conference in London, June 1946.

THE DOMINIONS

Canadian scientific institutions are included in the *Handbook* of those in the United States cited on page 193. The National Research Council, with its 11 laboratories and 33 Associate Research Committees to co-ordinate the work, carries out considerable research on behalf of industry.[1] The Ontario Research Foundation is pursuing long-term projects on carbon paper, cereal products, chewing gum, dental materials, electronic testing, fabrics, gas technology, high-temperature alloys, linseed oil, oil extraction, paper mill problems, pharmaceuticals, plastics, rayon, sole leather, steel plant technology, textile improvement, vegetable oil problems, wallpaper, welding and wood chemicals, besides providing a service for statistical quality control. Replies to a questionnaire sent out by the Canadian Manufacturers' Association to its 556 member firms, analysed in a special number of its journal *Industrial Canada* in January 1946, show

[1] See the review of its *Annual Report* for 1944–5 in *Nature*, 13 July 1946, pp. 68–9; also the paper on research in Canada read at the Royal Society of Arts on 13 April 1941, printed in that Society's *Journal*.

that 362 of these (whose addresses are given) maintain a laboratory for some kind of quality control or research: 324 also use their laboratories for improving existing products or techniques; a total of 3,189 persons are employed in these laboratories; and 280 of the firms spent a total of $11,000,000 on scientific research in 1944. Some 42 of the firms belonged to a Canadian trade research association doing collective research for them, especially the Canadian Pulp and Paper Association.

In Australia a Council for Scientific and Industrial Research has been formed by reorganising the Commonwealth Institute of Scientific and Industrial Research under the Scientific and Industrial Research Act 1920–37. It carries out researches connected with both primary and secondary industries which in 1938 included work on plants, soil, entomology, animal health, forest products including paper, food preservation and transport, radio, ore dressing, minerals and fisheries. The Council trains research workers and assists research students with grants. It was also aiming to set up a National Standards Laboratory at Sydney and an Aeronautical Research Laboratory at Melbourne.[1] The (separate) Standards Association of Australia, under the ægis of the Commonwealth and State Governments, besides formulating Australian standard specifications and codes, has a Power Survey Committee to assist in the development and co-ordination of power schemes, and it administers the Australian National Committees of the International Electrotechnical Commission, World Power Conference and International Commission on Large Dams.

[1] These notes are from the *Official Yearbook* of 1938, but *Nature*, 27 April 1946, pp. 545–6 gives more recent particulars. A lubricants and bearings section, set up in 1939 and collaborating closely with Cambridge, has been renamed the Tribophysics Section.

"Notes on the organisation of scientific research in New Zealand", by A. L. Poole, Liaison Officer of the New Zealand D.S.I.R. in London, appeared in the ASLIB *Report*, 1945, above mentioned and the Department's own *Annual Report* for 1944–5 including those of its constituent committees and institutions was reviewed in *Nature*, 6 July 1946, page 32. The latter include a Building Research Committee working on timber pests, prefabricated and pumice concrete, acoustics and earthquake proofing, and other committees interested in the refrigerated gas storage of apples, dehydration of food, linen flax, soil survey work, radio research, coal and mineral resources, and other matters. Experiments are conducted at the Cawthorn Institute, Dominion Laboratory (Chemical), several observatories and a Physical Laboratory on the lines of Teddington. A Manufacturers' Research Committee has been established and under the ægis of the Department there are two research associations, for wool and for leather and footwear. Besides separate bulletins it publishes a *Journal of Science and Technology*. Apart from this the Royal Society of New Zealand makes grants for research by independent individuals, and publishes its *Transactions*.

In South Africa a Council for Scientific and Industrial Research similar to those in the other Dominions is in process of formation under an Act of 1945. It will have a full time President responsible to the Prime Minister of the Union and nine members chosen for their eminence in science and industry. Its basic revenues are to be derived from a parliamentary vote intended always to be maintained at a reasonable working figure in accordance with the Government's policy of assisting stable productive employment in times of stress, supplementing the contributions by industry.[1] At present South Africa spends on research only

[1] *Nature*, 18 May 1946, page 652.

about one-sixth of the amount required for parity with other countries. The South African Sugar Association Experiment Station and the Timber Research Laboratory of the Chamber of Mines are financed wholly by industry and there are three other laboratories to which the Government also contributes, namely the Leather Industries Research Institute, the Fuel Research Institute and the Milling Laboratory at Stellenbosch. Proposals put forward apart from the C.S.I.R. include a South African Bureau of Standards with facilities for both testing and research, a National Institute for Personnel Selection and Research and compulsory efficient cost accounting (at present 75 per cent. of the manufacturers have none) in all industries enjoying state protection.[1]

INDIA

The history and functions of the Industrial Research Bureau which administers grants from the Government of India to scientific institutions, and its work in relation to vegetable oils, fertilisers, drugs, plastics, sulphur, optical and other scientific instruments, graphite and carbon electrodes, industrial fermentations, glass and refractories, dyestuffs, fuel research, cellulose, essential oils, metallurgy and naturally occurring salts have been briefly described by its Director, Sir Shanti Bhatnagar, in an article entitled "The organisation of scientific and industrial research in India", *Chemistry and Industry*, 29 November 1941, pp. 839–42. The Industrial Research Bureau is responsible to an Industrial Research Council under Government which issues an annual *Report* covering also the work of the Research

[1] *Investigation into Manufacturing Industries in the Union of South Africa.* S. A. Board of Trade and Industries, Report No. 282. Cape Town, 1945.

Branch of the Government Test House, which is a separate organisation.

Other research in India is conducted by the respective departments of Government concerned with various branches of engineering—such as, for instance, irrigation, in which connection there is a station for experiments on hydraulic models—and by private concerns. A useful journal, *Science and Culture*, is published in Calcutta and may be seen in London at the Science Museum Library and elsewhere. In 1944 an Indian Scientific Mission visited the United Kingdom to plan improved collaboration on matters of research, as discussed in *Nature*, 16 December 1944, pp. 756–7.

An institute modelled on the Mellon Institute in the United States (see page 190), to be known as the Lala Siram Industrial Institute, is contemplated at Delhi.

The Indian Jute Mills Association Research Institute, founded in 1937 with headquarters at Calcutta, maintains a branch office and laboratory in the Imperial Institute, London.

THE COLONIAL EMPIRE

Scientific research in the Colonial Empire is assisted from the Colonial Development Fund set up in 1929, out of which a total of £5,000,000 is authorised to be spent in ten years.

The Colonial Research Committee, whose *First Annual Report* was published for 1943–4, is a body of distinguished scientists under the chairmanship of Lord Hailey which was set up by the Secretary of State for the Colonies in 1942 and has initiated researches in agriculture, medicine and the social sciences. An extension of its scope in the direction of engineering and the industrial sciences may be expected in collaboration with the Imperial Institute and the Colonial Products Research Council. Dr. Glanville (on whose paper [82.1] this paragraph is based) stresses, in connection

with civil engineering researches, a point on which the present writer can bear witness from his own experience in the colonies: namely, the marked influence of local conditions—climate, soil, topography, mineral resources, labour conditions, the availability of plant, traditional methods—in determining the nature of civil engineering works (especially road building) in such countries, and, therefore, the character and organisation of the researches which ought to be associated with them. This being the case, some of the research establishments ought, Dr. Glanville suggests, to be located in the areas they are to serve, whilst those at home should undertake the bigger and more fundamental investigations, act as centres of information, and assist by training and exchanging personnel so as themselves to become more "colonial minded".

Apart from the ever-recurrent fact that all development in the colonies is conditioned by the engineering of means of transport, a fascinating and well-documented introduction to the sort of problems that are calling for solution not only in Africa but in tropical countries generally is available in *Science in Africa*,[1] a collective work consolidated by Dr. E. B. Worthington under the same auspices as Lord Hailey's monumental *African Survey* which is concerned with social, administrative and political problems in the same British and other territories south of the Sudan.

The scientific work needed in countries of this kind naturally has its centre of gravity somewhat displaced from that covered by the present book, the emphasis being more on human and veterinary medicine, agriculture and animal

[1] E. B. Worthington: *Science in Africa*—a review of scientific research relating to tropical and southern Africa. Issued by the Committee for the African Research Survey under the auspices of the Royal Institute of International Affairs (Oxford University Press, 1938), 613 pp. text + 78 pp. bibliography + 53 pp. index.

husbandry, zoology, fisheries, entomology, botany, forestry and other biological sciences besides the underlying geology and topographical surveying. But in these fields many questions arise—or at a later stage will arise—which impinge upon engineering or industrial science. Many examples in both these categories are discussed in the book. Among those that affect civil engineering work are the great and vital problem of soil erosion; the effect of irrigation in modifying the chemical constitution of agricultural soils; and the provision of water supplies whereby "the environment in many arid parts is being altered to an extent which must influence human customs and social behaviour"—as, for instance, in Northern Nigeria where the sinking of wells 150 feet deep, with modern pumps, is enabling the constant use of pasturages which formerly were available only in the wet season. Industrial examples include the protection of export produce against pests; the manufacture of bone-meal manure as a by-product from the meat factories which are being encouraged in order to combat overgrazing; and the development of fisheries and fish-meal manufacture to remedy deficiencies in native diets.

UNITED STATES

The volume of research done in the United States is far greater than in Great Britain whether measured absolutely or in relation to the gross expenditure on works. According to Dr. Glanville [82·1], however, it is on the whole less organised and integrated than in this country: a generalisation which he ascribes to the Americans being enabled by their great resources "to realise that it is better to get on with the job and risk a certain amount of overlapping. We in this country are more circumspect—by nature, and because we are compelled by force of circumstances."

The National Academy of Sciences at Washington corresponds broadly to our Royal Society. The equivalent of the British Standards Institution is the American Standard Association, whereas the National Bureau of Standards corresponds more to our National Physical Laboratory: it does not " approve " any particular material or method of construction but " determines technical facts, basing its reports so far as possible on objective tests in which the personal element is eliminated, and avoids the expression of opinions so far as is practicable. On the basis of tests at the Bureau and other pertinent data several Government agencies set up approved lists of products and appliances." (Quoted from a publication of the Bureau.)

The Engineering Foundation, occupying the Engineering Societies' Building, New York, is a joint organisation of the American Societies of Civil, Mining, Metallurgical, Mechanical and Electrical Engineers for " the furtherance of research in science and engineering and the advancement in any other manner of the profession of engineering and the good of mankind. . . . Its immediate objective is the furtherance of research by the Founder Societies and other engineering organisations ", but it " refrains from direct management and has no laboratories or staff of its own ", and is mainly concerned in " projects which are not likely to be undertaken by other agencies ". Progress on projects in hand is summarised in the *Annual Report* from which the above is quoted.

There is nothing in the United States corresponding to our Department of Scientific and Industrial Research, and the organisations concerned in addition to the above may loosely be divided into those which co-ordinate and assist with funds and those which actually conduct research. The following is a list of the more important of the first men-

tioned (quoting again mainly from [82.1] except where another reference is cited):

(1) At the Federal level, the National Research Council founded in 1916, which serves as a clearing-house for information about the natural sciences and their application. Its services are mainly bibliographical; but "through its Division of Engineering and Industrial Research, and to a lesser extent through others of its eleven Divisions, the National Research Council exercises a considerable influence over civil engineering as well as over other researches, and performs a valuable function in stabilising and providing 'ballast' for the tremendous surge of research activity. The Highway Research Board of the first-named division is a particularly live body."

(2) The American Society of Civil Engineers, "which, according to the 1943 *Handbook*, has twelve main technical divisions and 100 sub-committees considering and reporting on the several aspects of civil engineering. Not all of these committees are specifically concerned with scientific research, but . . . all are concerned in one way or another with advancing scientific knowledge . . . the main divisions . . . are City Planning, Construction, Engineering Economics, Highways, Hydraulics, Irrigation, Power, Sanitary Engineering, Soil Mechanics and Foundations, Structural, Surveying and Mapping, and Waterways."

(3) The American Railway Engineering Association which, in collaboration with the Association of American Railroads, "combines to a considerable degree the roles of a codes of practice committee, a research board, and a professional society", and co-ordinates researches carried out by the railway companies themselves, largely at universities and manufacturers' plants.

(4) The American Society for Testing Materials, which

again is concerned with standards, publishing *Tentative Specifications* which later are reissued as *Final.*

(5) Such bodies as the Mellon Institute of Industrial Research, which provides for co-operative work among manufacturers. The Mellon Institute does about a quarter of its work on what is called the "industrial fellowship" system and has, since its establishment in 1913, benefited in this way many hundreds of technical subjects, resulting in the invention and development of new products and processes and even in new industries.[1]

The main organisations which actually carry out researches as distinct from co-ordinating them are :

(*a*) The following Federal Government departments [82·1], whose publications are issued through the U.S. Government Printing Office, Washington, D.C. :

Department of Commerce :
- National Bureau of Standards (see above).
- Civil Aeronautics Administration.

Department of the Interior :
- Bureau of Mines.
- The Geological Survey.
- Bureau of Mineral Statistics and Economics.
- Bureau of Reclamation.

Department of Agriculture :
- Forest Service.
- Bureau of Chemistry and Soils.
- Bureau of Agricultural Engineering.
- Soil Conservation Service.

Federal Works Agency :
- Public Roads Administration.

War Department :
- Corps of Engineers, U.S. Army.
- Bureau of Yards and Docks, U.S. Navy.

[1] W. A. Hamor : U.S. portion of article on "Research, Industrial", in *Encyc. Brit.*

Independent Federal Agencies:
Tennessee Valley Authority.
Panama Canal Authority.
U.S. National Resources Planning Board.

(*b*) Counterparts of the above exist, to some extent, within the administrative frameworks of some of the individual States and local authorities, particularly as regards road research.

(*c*) Independent research institutes, including many of large size operating on funds assigned to them by wealthy benefactors, and some 300 or more consulting laboratories which carry out research as well as testing for firms that have no laboratories of their own.

(*d*) Universities, in much larger volume than is the case in Great Britain, largely through the support of industrial interests. An article by C. Hull and M. Mico: Research supported by industry through scholarships, fellowships and grants, *Journal of Chemical Education* (New York), April 1944, pp. 180–91 gives a list of 201 companies which, in the previous year, had reported a total of 956 awards of this kind, the largest numbers being for researches in chemistry, engineering, food and nutrition.

(*e*) Trade associations, such as the Portland Cement Association, the Asphalt Institute, the Brick Manufacturers' Association and many others, which either have their own laboratories or operate through the universities by endowing Research Foundations, or co-operatively with Federal and State laboratories[82.1].

(*f*) Industrial firms. Fifteen years ago these were estimated to be spending over $100,000,000 a year on research and to be employing some 16,000 scientists and engineers for the purpose. Nearly one-half of the total was being spent on chemical investigations in the plant

laboratories of the companies concerned. The largest single establishment in this category, that of the Bell Telephone Company, was then stated to be employing 2,000 physicists, chemists and engineers.[1]

An official survey, under the title *Research—A National Resource*, has been produced by the National Resources Committee in three volumes as follows :

I. *Relation of the Federal Government to Research* (1938. 263 pages).
II. *Industrial Research* (1941. 382 pages).
III. *Business Research* (1941. 80 pages).

The 1942 edition of the *Handbook of Scientific and Technical Societies and Institutions of the United States and Canada*, published by U.S. Government Printing Office, Washington, refers to 1,269 such organisations in the United States and 143 in Canada, giving some 100 to 200 words of information about each, including the names of the chairman and secretary, and notes on the history, objects, membership, meetings, library, research funds and publications of the organisation concerned.

For a reasoned unofficial account of the subject, including five pages of bibliography, see H. R. Bartlett : The development of industrial research in the United States, *Journal of the Patent Office Society* (Washington), August 1941, pp. 589–614, and a book by R. S. Bates : *Scientific Societies in the United States* (New York : Wiley, and London : Chapman & Hall, 1945). The latter includes tables showing the distribution of American scientists according to branches of science, belonging to one or more societies or none.

During the war Dr. Vannevar Bush, as Director of the Office of Scientific Research and Development, co-ordin-

[1] For a description of the new Research Laboratories Building of the Bell Telephone Company at Murray Hill, N.J., see *Engineering News Record* (New York), 26 Feb. 1942.

ated the activities of some 6,000 leading American scientists in the application of science to warfare. To improve liaison between the two countries this Office set up a Mission in London, whilst a British Commonwealth Scientific Office was opened in Washington, whereby exchanges of data and personnel were arranged as described in an article by A. King in *Nature*, 19 January 1946, pp. 63–4.

SOVIET UNION

The keystone of scientific organisation in the U.S.S.R. is the Academy of Sciences which comes under the direct jurisdiction of the Council of People's Commissars and is State-supported on a generous scale. The Academy's task is to promote the general development of both theoretical and applied science through the medium of about 80 research institutes. There are also research institutions and laboratories run by Commissariats, scientific societies and universities, but these appear to occupy a subordinate place as compared with those under the Academy.[1]

British scientists who visited Moscow and Leningrad in the summer of 1945 were impressed with the diversity and quality of the work in progress and of the equipment in use; also with the way that abstract and applied researches were typically being pursued side by side in a single institute. For instance, fundamental work on the electrical and mechanical properties of solids was being carried on together with the preparation of rectifiers and the investigation of dielectric problems with practical ends in view. Organic chemists were found to be concentrating largely on problems relating to actual or potential industries, especially petroleum.

[1] Since its first appearance in 1836 the several sections of the Academy's *Bulletin* have undergone so many changes in scope and in the extent that translations or summaries in Western languages are provided, that these are difficult to follow. A detailed account of them is given by T. Besterman in *Journal of Documentation*, Vol. 1, June 1945, pp. 45–56.

Much attention is being paid to " pedology " or soil science, a field in which many branches of Soviet science meet, as, for instance, where an eminent physicist is engaged on new methods for measuring the temperature of soil surfaces and on the insides of leaves. " The Russians . . . were the first to recognise the distribution of the main types of soil in the world and they evolved the first natural system of soil classification. On this system they have made general soil maps not only of the whole of the U.S.S.R. but of Australia, Africa and South America." [1]

Russian scientific journals are obtainable from Mezhdurarodnaya Kniga, Moscow, through Collets Foreign Department, 67, Great Russell Street, London, W.C.1, who state that most of the regular publications have been supplied throughout the war. The list obtainable from Collets, entitled *Periodica U.S.S.R.*, includes, among others, about 30 titles which may loosely be classed under the heading of industrial science. Among these, *Acta Physicochimica* and the *Journal of Physics* contain articles in English, French or German, as well as Russian.

GERMANY

Since the defeat of Germany many visits of inspection have been paid to industrial plants and laboratories in the British and American zones of occupation by official Allied teams of technicians. Some of the reports containing the results of their observations and interrogations of German technicians are being published by H.M. Stationery Office. These vary in length, scope and quality but often present data which are of value for comparison with our own industrial practice and research. The earlier reports bear numbers

[1] *The Times*, 7 July 1945, p. 5. For a longer account see K. G. Naik : Organisation of scientific research in the U.S.S.R., *Science and Culture* (Calcutta), March 1944, pp. 365–6, and less recently S. P. Turin : Scientific and technical research in Soviet Russia, *Rept. 14th Conf. ASLIB*, 1937, pp. 49–58.

preceded by the letters C.I.O.S. meaning Combined (i.e., American and British) Intelligence Objectives Sub-committee. Later British reports are designated B.I.O.S. and some American reports F.I.A.T. (Field Intelligence Agency Technical). Lists of these reports appear in the *Board of Trade Journal*, as do lists of public libraries throughout the country where they are available for reference.

In addition many tons of captured German technical documents of all kinds, varying from single sheets to voluminous research and operating reports, have been brought to this country or to the United States. The former are held in London at the Foreign Documents Library of the Board of Trade, where summaries in English of the more important are being made. By arrangement it is possible for these documents to be studied in the library. The originals are not allowed to be taken away but microfilm copies of them can be supplied at cost.

At a conference on German patents held in London in July 1946 it was agreed that patents formerly held by German nationals in the territories of the principal allied countries, including the United Kingdom, should be made available to all nationals of those countries without payment of royalties or requirement to manufacture locally.

VISITORS TO BRITAIN

The Society for Visiting Scientists, founded in 1944 under the joint auspices of the Royal Society and the British Council, offers assistance in the way of contacts and information as well as the amenities of a club to scientists from overseas visiting Britain. It is open to all such visitors of recognised academic standing on payment of an entrance fee of five shillings, with no subscription unless the visitor stays here longer than six months. The address is 5, Old Burlington Street, London, W.1.

CHAPTER SIX

THE COLLECTION OF DATA FROM TECHNICAL LITERATURE

INTRODUCTION

THIS chapter and the next are the most important in the book, relating as they do to a branch of scientific work which is relatively neglected. Through such neglect hundreds of thousands of pounds are wasted annually on the working out of engineering projects, the development of inventions and the conduct of experimental researches which might either be saved altogether or be begun from a more advanced starting-point if the technique of finding out what other workers have already done and placed on record were better understood. But, for some reason difficult to perceive, the laboratory worker reading a gauge or shaking and looking at a test-tube enjoys support and prestige denied to the bibliographer and writer concerned in the later processing and utilisation of the raw material of knowledge so obtained.

It is true that most technical men read occasional books and make some attempt to follow the periodical press relating to their subjects, and in many organisations the practice is followed of passing journals round for perusal by each member of the staff concerned. Such haphazard reading of current issues is not, in moderation, waste of time. A well-edited journal has characteristics of unity, selectiveness and topicality which make it something more

than merely a collection of articles strung together for reasons of economy; and this quality, while difficult to define, is educationally valuable. The organ of a profession tends to reflect, in its tone and choice of emphasis, the composite mind of that profession, and a reader's mind is thereby matured and stimulated.

But as a means of accumulating information—specific and potentially useful ideas—unplanned reading is inefficient. As the figures presently to be quoted will suggest, the chances must be hundreds to one, even within a limited field of knowledge, against an individual having run across *the best* reference for his purpose in the small group of journals and books he can find time to look at within the recent period to which his memory extends. Nor will the index included in the annual volume of each particular journal greatly help him, for this affords no clue to what has appeared in the many thousands of other journals, and he cannot search them all. For him to take notes on what he happens to find is merely to duplicate in an amateur and uncertain way what is already being done more fully and systematically by the organised compilers of abstract publications mentioned below.

The basic problem of documentation—to introduce the ugly but comprehensive word of French origin which covers what is now to be discussed—resides in the fact that on the one hand every man's time is limited, while on the other hand there must exist, somewhere among the millions of documents annually poured forth, the particular ones bearing the ideas most apposite to his needs if only he could single them out from the mass. A technical man's time and attention are precious things which must be husbanded: they ought not to be frittered away in reading any document which is not the *best possible one* for the immediate

purpose, or in searching through the jungle growth of knowledge without a reconnaissance map to guide him.

Aids to reconnaissance in this sense—which in literary as in geographical exploration should precede more intensive survey—are more numerous than is generally realised and it will be the object of part of this chapter to give some account of them.

ORIGINAL PUBLICATIONS

Original published records of technical information will be considered here in seven categories, the first of which is the most voluminous and important :

(1) Periodicals, including both independent journals and the transactions or proceedings of societies. The contents of the former are known as " articles " and of the latter as " papers ". They may be by one or more authors and vary in length from 1,500 to 15,000 words, but are seldom longer. Before the war it was estimated that some 14,000 periodicals, in all languages, were appearing in reference to what may broadly be classed as engineering and industrial science, containing, each year, roughly 750,000 articles and papers.

The *World List of Scientific Periodicals* (Oxford University Press, 2nd edn., 1934), covering all branches of science including those considered here, gives 36,000 names of journals in alphabetical order, both in full and as abbreviated for purposes of citation in accordance with certain internationally agreed rules ; also indications of which years' run (if any) of each periodical are available in each of 44 London and 133 other British libraries.

The *Hand List of Short Titles of Current Periodicals in the Science Library* (Part 1, alphabetical ; 5th edn., 1938) contains about 9,000 main entries ; Part 2, arranged under subjects, was to appear later.

E. J. Crane and A. M. Patterson : *A Guide to the Literature of Chemistry* (New York : Wiley, 1927) includes annotated lists of the principal chemical and other scientific journals in many countries, and much useful advice on searching.

(2) Specific reports and other separately published papers

of the kinds discussed in this book on page 174 under the heading " Collation of knowledge from practical experience ".

(3) Specific reports and separately published papers on researches, including university theses.

A symposium on " The accessibility of the thesis literature of the world " appeared in *Rept. 16th Conf. ASLIB*, 1939 (see page 219). No central catalogue of British university theses exists. The Library of the University of London contains all successful theses presented at that university whether published or not, in addition to about 10,000 (not all on scientific subjects) from certain foreign universities. The British Museum also contains collections of foreign theses. In the United States, lists of doctoral dissertations are compiled by the Library of Congress and published from time to time in *Science*, the *Reprint and Circular Series* of the National Research Council, and elsewhere. There is also an annual list, *Doctoral Dissertations Accepted by American Universities* (New York : H. W. Wilson Co.), which for 1938–9 recorded 2,928 theses including, for the first time, a note of those available on film. In France there is an annual *Catalogue des Thèses et Ecrits Académiques* (Paris : Leroux) classified by institutions under main subjects. In Germany, where the *Doktor-Dissertationen* play an especially important part in technical literature, there is (or was) an annual *Jahres-Verzeichnis der an deutschen Universitäten erschienen Schriften* (Berlin : Behrend).

(4) Separate books, of which about 14,000 on technical subjects used to appear annually in all languages. As vehicles of *new* knowledge these are less important than the above-mentioned, their period of gestation being so much longer and their production slower and more cumbrous. They may be divided broadly into textbooks for educational purposes and treatises which are in the nature of reviews—using that term as explained in the next section—of particular fields of knowledge.

A. D. Roberts : *Guide to Technical Literature* (London : Grafton & Co.) is mainly a selected book list containing English, German and a few French and other titles, arranged in chapters under subject headings. The first volume, composed of *Introductory Chapters and Engineering*, appeared in 1939 and another dealing with chemical technology was to follow. Language dictionaries,

indexes and bibliographies and works of general reference are usefully mentioned at the beginning of each chapter.

The quarterly *ASLIB Book List* and its collective index for the years 1935–44 (see page 219) are valuable, especially for the stocking of a library.

In 1946 the U.S. National Research Council issued a catalogue of scientific and technical books published there from 1930 to 1944.

(5) Works of reference: these differ from the above in that they are not intended to be read through at the time of acquisition but need to be kept at hand: (*a*) to give the values of physical constants indispensable for translating algebra into arithmetic as here explained on page 43 under the heading " Measuring the characteristics of the available materials ", and (*b*) to fill gaps in an individual's knowledge in circumstances where the trouble of referring to original sources is not warranted. (Encyclopædias become out of date even quicker than the books mentioned in the preceding paragraph. Mr. H. G. Wells has advocated a vast extension of the encyclopædic idea, but it may be questioned whether the effort involved might not be better spent on so improving and rationalising the machinery of bibliography and the distribution of books, journals and microfilms as make the world's literature as a whole serve as a ready-made encyclopædia never out of date.)

Purpose (*a*) is served by the *International Annual Tables of Constants and Numerical Data* published in French by Hermann et Cie, Paris, and in English by McGraw-Hill, New York. Begun in 1909 as a supplement to existing handbooks, this work had expanded by 1937 to include not only numerical data but a comprehensive bibliography and critical review of each section of science (see the review in *Nature*, 7 May 1938), thereby serving purpose (*b*) as well. Since 1941 the contents of the *Annual Tables* have been obtainable on 5 in. × 3 in. index cards (e.g. Bromine has 18 cards) from Frick Chemical Laboratory, Princeton, N.J., U.S.A. The price is 5 cents per card.

For many engineering and other purposes a combination of (*a*) with (*b*) is provided in such works as Kempe's *Engineers' Year Book* and the like.

Encyclopædias proper, serving purpose (*b*), include not only general works such as the *Britannica* and *Chambers*, but specialised publications such as Thorpe's

Dictionary of Applied Chemistry (London: Longman, 4th edn., 1938), Kingzett's *Chemical Encyclopædia* (London: Baillière, Tindall & Cox, 5th edn., 1932), Van Nostrand's *Scientific Encyclopædia* (London: Chapman & Hall, 1938), and *Hutchinson's Technical and Scientific Encyclopædia* (London: Library Press, *undated*). A useful quasi-encyclopædic work is that edited by M. D. Curwen: *Chemistry in Commerce* (London: Newnes, 1934—originally in 32 weekly parts) which explains a great variety of industrial processes and testing routines, following the plan of a visit to the works in question.

(6) Patent specifications. Before the war the annual production of these in all countries was approaching 200,000. Apart from their juridical importance they provide a valuable (and in some cases the only) bibliographical source for details of construction, and a historical survey of development. See pages 75 and 224.

J. Alingh Prins in his paper "Patent literature as a source of technological documentation" in *Report of the Internatl. Inst. of Docmn. Confce., Copenhagen*, 1935, states that patent literature, as a source of information, is two or three years in advance of periodical literature.

(7) Catalogues and advertising matter.

It would not be logical to place Government publications in a category by themselves as they include examples of practically all the above; but it is important to appreciate what an extraordinary variety of technical as well as other subjects, from Aeronautics to X-rays, they do cover and how great is the likelihood of finding among the publications of His Majesty's Stationery Office [1] the most authoritative and exhaustive survey of some subject which has been investigated by a commission, the most illuminating account of some branch of technical administration, the most concise instructional manual, the fullest source of industrial statistics,

[1] The annual *Consolidated List of Government Publications* and *List of Publications of the D.S.I.R.*, etc., are fully indexed and the *Guide to Current Official Statistics* provides an admirable example of the value of cross-referencing.

or the most interesting history of some branch of technology. The corresponding publications of Dominion governments and particularly those of the U.S. Government Printing Office, Washington, D.C., should also be remembered.

Technical knowledge at various stages of ripeness is contained, apart from publications, in the unpublished reports, memoranda, minutes of meetings, logs of operating data, calculations, drawings and other records which abound within every organisation or firm. The aggregate volume of these papers probably exceeds that of publications, and their importance to those whom they concern may justify an internal counterpart of the machinery which exists, and is now to be discussed, for the indexing and abstracting of published literature.

RECONNAISSANCE BY MEANS OF REFERENCES AND ABSTRACTS

A printed text, in itself, is inert. It can be transmuted into active knowledge only through the assimilative effort of a human mind, by being read. But a reader's power of concentrated attention wanes if he reads too long, and yields "diminishing returns" for the time and effort so expended. Hence the reading of full texts should be economised by first reconnoitring the field to determine which of them are best worth reading.

Such reconnaissance may be effected by direct reference to a card index as described in the next chapter or by the use of abstracts and other published bibliographical aids as will now be discussed. In many cases these are compiled from such an index maintained at a central point and in all cases they may, of course, be looked upon as material for incorporation in a card index of one's own, where such is desirable, as suggested in the next chapter.

Three objectives will be distinguished :

(*a*) The ensuring of continual awareness, by an individual, of current developments in some field of science.

(*b*) The conduct of a formal " literature search " to collect and collate all the relevant knowledge on some given topic.

(*c*) The maintenance of a personal collection of published combined with other data at the user's finger-tips to serve both as material for his specific researches and as a background for his day to day thoughts on technical matters.

The table on pages 206 and 207 contains the names of bibliographical aids relating to the subject matter of this book which are themselves printed in English, though in nearly every case the journals to which they refer include those in foreign languages also. They are classified, horizontally and vertically as shown in the key diagram, on a plan which facilitates discussion of their respective utility for the three purposes (*a*), (*b*) and (*c*) as defined above.

Those corresponding to column 1 of the key diagram are publications which appear monthly or otherwise without any attempt at continuous itemised indexing ; hence they are primarily of use for a reader to look through as and when they come out, with a view to keeping himself generally informed as to what is being published on the subjects which concern him, and making sure that he is not missing anything of importance in those fields. In other words, they are of use for purpose (*a*) but are of little help for assembling back references, purpose (*b*).

The publications classed in column 2 are rather more useful for back reference because, on the completion of each annual volume, an itemised subject index is published whereby one can find all the references to any given subject which have appeared in that period. The index, however, is not continuous from year to year, and if it is desired to make a

KEY TO CLASSIFICATION OF REFERENCES AND ABSTRACTS

FORM OF ISSUE

MORE USEFUL FOR CURRENT PERUSAL ← → MORE USEFUL FOR BACK REFERENCE

DEGREE OF FULLNESS: MORE USEFUL FOR EXTENDING THE RANGE OF AWARENESS OF WHAT IS AVAILABLE ↑ ↓ MORE USEFUL FOR DETAILED STUDY OF A LIMITED RANGE OF SUBJECT MATTER

IN PAMPHLET FORM OR INCLUDED IN JOURNALS, WITHOUT INDEX (1)	AS (1), BUT COVERED BY SUBJECT INDEX AT END OF YEAR (2)	BOUND VOLUMES IN DICTIONARY FORM (3)	ARRANGED FOR CUTTING OUT AND PASTING ON TO CARDS (4)	PRINTED ON INDEX CARDS (5)
A.	TITLES AND	REFERENCES	ONLY	
B.	ANNOTATED	TITLES AND	REFERENCES	
C.	SHORT ABST	RACTS		
D.	LONGER ABS	TRACTS		
E.	REVIEWS			
F.	FULL TEXT	OF ORIGINAL	PAPERS	
G.	READER'S O	WN NOTES F	ROM STUDY	OF ORIGINAL

The Science Museum Library *Bibliography of Current Periodical Abstracts and Indexes*, details (in the 1934 edition, since revised) 326 of these in various languages, and has been used as a source of material for the present table which the author desires gratefully to acknowledge. He has added other and more recent items. In many cases minor subjects even if separately mentioned are also included in the scope of the major. (*Engineering Abstracts* on which several engineering institutions collaborated until the war (see page 146), since discontinued, was of type D.2 above and covered only foreign journals. It had latterly been issued in four separate parts: (1) Engineering Construction, (2) Mechanical Engineering. (3) Shipbuilding and Marine Engineering, and (4) Mining Engineering.)

BIBLIOGRAPHICAL AND ABSTRACT SERIES IN ENGLISH, COVERING PUBLICATIONS ON ENGINEERING AND INDUSTRIAL SCIENCE

Subject	*Title or description*	*Key*	*Issue*
References to periodical literature as well as books:			
Aeronautics	*Index Aeronauticus* (Min. of Supply, London)	A.1	Monthly
"	In *Journ. Roy. Aeronautical Soc.*	D.2	Monthly
Atmospheric pollution	*Atmospheric Pollution Abstracts* (D.S.I.R.)	C.1	2 yearly
Building	*Building Science Abstracts* (D.S.I.R.)	D.2	Monthly
"	*Library Bulletin* of Ministry of Works	B.1	Fortnightly
"	Abstract Section of *Architects' Journal*	D.2	Weekly
Ceramics	*Ceramic Abstracts* (Easton, Pa.)	C.2	Monthly
Chemistry	*British Abstracts*—see page 218		
"	A.I *General Physical and Inorganic Chem.*	C.2	Monthly
"	A.II *Organic Chemistry*	C.2	Monthly
"	A.III *Physiology, Biochemistry, Anatomy*	C.2	Monthly
"	B.I *General and Industrial Inorganic Chemistry (including Metallurgy)*	C.2	Monthly
"	B.II *Industrial Organic Chemistry*	C.2	Monthly
"	B.III *Agriculture, Foods, Sanitation*	C.2	Monthly
"	C. *Analysis and Laboratory Apparatus*	C.2	Quarterly
"	*Chemical Abstracts* (New York)	C.2	Fortnightly
Concrete	In *Journ. American Concrete Inst.*	C.1	Monthly
Dyeing	In *Journ. Soc. Dyers and Colourists* (Bradford)	D.1	Monthly
Electroplating	In *Rev. Amer. Electroplaters' Assoc.*	D.1	Monthly
Engineering—			
All branches	Lists of contents in current numbers of certain journals such as *The Engineer* are so printed that each item is a complete reference, including name of journal and date	A.4	Weekly
"	*Engineering Index* (New York)—see page 208	B.3	Yearly
"	*Engineering Index Service* (New York)—see page 208	B.5	Weekly
"	*Engineers' Digest* of eng'g progress abroad	E.2	Monthly
Aerodrome	*Aerodrome Abstracts* (D.S.I.R.)	C.1	Monthly
Automobile	In *Journ. Inst. Automobile Engineers*	C.2	Monthly
Bridge and Structural	*Bull. Intl. Assoc. Bridge and Strl. Eng.* (Zürich)	*C.1	Monthly
Civil	Part of *Eng. Index* reprinted in *Civ. Eng.* (N.Y.)	B.4	Monthly
Electrical	*Science Abstracts B*	D.2	Monthly
Irrigation, etc.	Cent. Bd. of Irrign. *Abs.* (Simla) (U.)	C.1	Fortnightly
Mechl. and Electrical	*Technical News Bull.* of Metrovick Ltd. (U.)	D.4	Weekly
Production	In *Journ. Inst. Production Engrs.*	C.1	Monthly
Public works	Min. of Works *Library Bulletin* (U.)	B.1	Fortnightly
Experiment tank work	Science Library *Current Reference Lists* (U.)	A.4	As necessary
Fibres	*Natural & Synthetic Fibres Abs. Service* (Mark & Proskauer, New York)	D.5	
Food	*Index to Lit. of Food Investign.* (D.S.I.R.)	C.1	2 each year
Fuel utilisation	*Fuel Abstracts* (D.S.I.R.) (Dewey nos.)	D.2	Monthly
"	Br. Coal Utiln. Res. Ass. *Bulletin*	C.2	Monthly
Geophysics, Applied	Science Library *Current Reference Lists* (U.)	A.4	As necessary
Glass	In *Journ. Inst. Glass Technology* (Sheffield)	C.1	Monthly
Industry—			
General	*Industrial Arts Index* (New York)	A.2	Monthly
Hygiene	In *Journ. Indl. Hygiene and Toxicology* (New York)	C.2	Monthly
Instruments	In *Bull. Br. Sc'c Inst. Res. Assoc.*	B.1	Monthly
Kinematography	In *Journ. Soc. Motion Picture Engrs.* (New York)	A.1	Monthly
Lighting	In *Light and Lighting*	C.1	Monthly
Lubrication	Science Library *Current Reference Lists* (U.)	A.4	As necessary
Metallurgy—			
All branches	Part of *Eng. Index* reprd. in *Metal Progress* (Cleveland)	B.4	Monthly
"	*Metallurgical Abs.* in *Journ. Inst. Metals*	C.1	Monthly
"	In *Metals and Alloys* (New York)	D.1	Monthly
Foundry work	Part of *Eng. Index* reprinted in *Bull. Amer. Foundrymen's Assoc.* (Chicago)	B.4	Monthly
Iron and steel	In *Iron, Steel and Industrial Fuel*	C.4	Monthly
Light metals	In *Light Metals*	D.4	Fortnightly
Nickel	In *Nickel Bulletin*	D.1	Monthly
Non-ferrous	*Bull. Brit. Non-Ferrous Metals Res. Assoc.*	C.1	Monthly
Mineralogy	*Mineralogical Abstracts*	C.2	Quarterly
Mining	Safety in Mines Res. Bd. *Bibliog. of Curr. Periodl. Lit.*	B.1	Monthly
Mining and Metallurgy	Part of *Eng. Index* reprinted in *Bull. Inst. Mining and Metallurgy* (New York)	B.4	Monthly

Subject	*Title or description*	*Key*	*Issue*
References to periodical literature as well as books:			
Oils and Colours	In *Journ. Oil and Colour Chemists' Assoc.*	A.1	Monthly
Optical mechanisms	In *Dioptric Review*	A.1	Monthly
Packaging	*Packaging Abstracts*		Monthly
Paints	*Rev. Curr. Lit. Paint, Colour and Varnish Industs.*	C.4	2 each month
Paper	In *Paper Trade Journ.* (New York)	C.1	Monthly
Petroleum	In *Journ. Inst. Petroleum*	C.1	Monthly
Photography	*Photographic Abstracts*	C.1	Monthly
Physics	*Science Abstracts A*	D.2	Monthly
,, at N.P.L.	*Abstracts of Papers, Nat. Physl. Lab.* (D.S.I.R.)	D.2	Yearly
Plastics	In *Modern Plastics* (Easton, Pa.)	C.1	Monthly
,,	*Resins, Rubbers and Plastics Abs. Service* (Mark & Proskauer, New York)	D.5	
Printing	*Printg. and Allied Trades Res. Ass. Journal*	C.2	Monthly
Railways	*Railway Eng'g Abstracts* (U.)	C.1	Fortnightly
,,	*Bibliography of Railways* (Brussels) (U.)	*A.1	Monthly
Refrigeration	*Intl. Bull. Infmn. on Refrigeration* (Paris)	*D.1	Fortnightly
Roads	*Roads Abstracts* (D.S.I.R.)	D.2	Fortnightly
Rubber	*Summ. Curr. Lit. Res. Assoc. Br. Rubber Mnfrs.* (Croydon)	C.4	Monthly
Science—			
All branches	*Repertorium Technicum* (6, Willem Witsenplein, The Hague) (U.)	*A.5	Fortnightly
Textiles—			
All branches	In *Journ. Textile Inst.* (Manchester)	C.1	Monthly
Cotton	*Summ. Curr. Lit. Br. Cotton Ind. Res. Assoc.* (Manchester)	C.4	Monthly
Linen	*Summ. Curr. Lit. Linen Indust. Res. Assoc.* (Belfast)	C.4	Monthly
Water pollution	,, ,, ,, *Water Pollution* (D.S.I.R.)	C.2	Monthly
Waterways	*Bibliogl. Notes on Rivers, Canals and Ports* (Brussels)	*A.1	5 each year
Welding	In *Welding Journal* (New York)	B.1	Monthly
References to articles in 531 British and American and 44 other periodicals on *all* subjects except verse and fiction, excluding those covered by *Eng. Index* and certain others above:			
	Industrial Arts Index (New York)	A.1	Monthly cumlve.
References to books only:			
All subjects	Publishers' book lists, library accession lists	A.1	Various
,,	*ASLIB Book List* of selected books	B.1	Quarterly
,,	Reviews appearing in most technical journals	E.2	Various
,,	*Library of Congress Cards* (Washington)	C.5	Fortnightly
,,	*Subject Index to Periodicals* (Library Assocn., London)	B.3	Yearly
,,	*British Book News* (Natl. Book League)	C.1	Monthly
Engineering—Mechanical	In *Journ. and Proc. Inst. Mech. Engrs.*	C.2	Monthly
Other papers classified in accordance with Key Diagram:			
All subjects	Patent Specifications	F.2	—
,,	Abridgements of Patent Specifications	*D.2	—
,,	Articles in technical journals	F.2	Various
,,	Articles, company reports, etc., in most newspapers	F.1	Daily
,,	,, ,, ,, ,, in *The Times*	F.2	Daily
,,	Notes kept in the form of a card index as recommended on page 261	G.5	—

* denotes publication interrupted by the war.
U denotes contents marked with Universal Decimal Classification index numbers.
Place of publication is London except where otherwise mentioned above.

search extending over several years back this means looking for the required item in several successive indexes, noting the page numbers given, and referring to each of them in turn in order to see whether it is what is required: a process so laborious that in practice, although it may be

undertaken for purpose (*b*) it will not be undertaken for purpose (*c*).

(In some cases a consolidated index is published after every few years' run, but this does not help matters in the meantime which is when the references, being fresh, are most likely to be required.)

A volume in dictionary form as in column 3, such as the *Engineering Index* described below, is much quicker to use than one in which the indexing is separated from the contents, but there is still the need to consult it separately for each year when using it for purpose (*b*), and its infrequent and delayed publication makes it almost useless for purposes (*a*) and (*c*) on page 204.

The publications classed in column 4 differ from those in columns 1 and 2 in that the references are printed either on one side of the paper only, or with advertisements on the back, so that they readily lend themselves to cutting out, pasting on cards, and dropping into place in a card index which may be made continuous and cumulative over any number of years, the cards relating to any given subject being then found together regardless of their origins and dates of publication. (If it is desired to take cuttings for this purpose from publications in columns 1 or 2, duplicate copies of them must be bought as there is text on both sides of the paper. Also, the fact that the items run on from page to page makes the job of pasting them on to separate cards more troublesome.)

Finally, column 5 refers to media like the *Engineering Index Service*, whereby the references are distributed to subscribers printed directly on cards with this object, so that scissors and paste work is saved.

As is suggested by the arrows at the top of the key diagram on page 205, the utility of these various systems for purpose

(*a*) on page 204 increases towards the left and for purposes (*b*) and (*c*) towards the right; a continuous, cumulative card index being by far the most convenient form for back reference. New batches of cards about to be added to such an index can, of course, first be passed round to interested readers in order to serve purpose (*a*) as well, but they are less convenient for this than are references in pamphlet form and are apt to get lost if allowed out of the room where the index is kept.

The scheme of vertical classification adopted in the key diagram is as follows. The items in line A give merely the titles and dates, etc., of the articles to which they refer: in other words, they make no attempt to transmit the knowledge-content of the original, but only furnish awareness of its existence. This limitation favours quickness of publication.

As every researcher knows, however, the unaided titles of articles frequently give a misleading indication of the contents, and to avoid the waste of time involved in turning up the wrong articles it is a great advantage if the titles can be followed by a few lines of explanation as at B.

By far the most complete publication in this category is the *Engineering Index*[1] of which there is a copy in every well-equipped engineering library in London; yet I am continually being astonished by meeting with engineers who have never heard of it. Its best-known form is an annual

[1] The *Engineering Index* and *Engineering Index Service* are owned and carried on by the American Society of Mechanical Engineers at the Engineering Societies Library, 29 West 39th Street, New York, N.Y., where all the publications indexed are permanently filed and photoprints or technical translations of the complete text of any article may be procured at cost. What makes this service financially possible is the fact that the library building was a free gift and is exempted from local taxation.

volume (column 3) containing well over a thousand pages and costing £13 upwards, in which are some 50,000 references with an average of about 35 words of annotation covering the contents of over 2,000 journals which include the transactions of some 500 technical societies, several hundred miscellaneous reports and about 500 new books. The subject matter extends to every branch of engineering in the widest sense of the word. About one-half of the periodicals covered are published in the United States and the remainder in 39 other countries; two-thirds of them are in English and the rest in 20 other languages; but the abstracts of them appearing here are all in English.

As indicated in class B.4 there are several American journals which, by arrangement with the *Engineering Index*, reprint month by month in their own columns (with advertisements on the back) the abstracts which afterwards are assembled in the annual volume described above; but only, of course, in reference to the specialised selections of subject matter which concern those journals.

Another alternative, known as the *Engineering Index Service*, is to subscribe direct to any of the desired subject divisions in the form of weekly batches of standard 5 inch by 3 inch library cards (class B.5) which are prepared in typescript from wax stencils; the subscription varies from \$7 to \$50 a year according to the scope of the division selected and would total \$3,686 (over £750) if all 278 divisions were taken. Two hundred of the American subscribers have these card abstracts posted to them daily on the afternoon of the same day that the original publications are delivered to the *Engineering Index*.

The *Engineering Index* covers books as well as journals, but so far as books are concerned a more complete and cheaper service is available in the form of the *L.C. Printed*

Cards[1] of standard 5 inch by 3 inch size, obtainable from the Library of Congress at Washington for practically every book as soon as published. (Also retrospectively; e.g. " all cards for books on Forestry published since 1900 ".) Each card bears the title, author and full description of one book and usually a list of the chapter headings or other indication of the contents, with classification numbers both on the Dewey decimal and the Library of Congress systems. Subscriptions can be taken out for all the cards relating to any particular division of science, and a standing order may be given for sufficient duplicate copies of the cards to enable the cross-referencing of each title collected. The cost works out at about 2*d*. a card. A still cheaper method is to subscribe to proof sheets of the cards containing five titles each.

Proceeding further down the table we reach those bibliographical publications which not merely ensure the searcher's awareness of the existence of items of knowledge but enable him to obtain an idea of their actual contents. These have been divided between C, Short Abstracts, and D, Longer Abstracts, though actually the latter vary in length, the references to the less accessible foreign papers being frequently made more exhaustive than those to English papers which anyone can easily obtain. It has been thought useful to distinguish a separate category E, Reviews, the difference between a review and an abstract being that the former implies the exercise of a critical selective faculty by the reviewer, whereas an abstractor, it may be argued, should compress but not select, paying uniform attention to all parts of the ground he covers. Such a category would include not only book reviews in the ordinary sense but the other

[1] There is a small pamphlet in the Science Library by C. H. Hastings: *L.C. Printed Cards—how to order and use them* (Washington: L. of C., 1925).

contents of the quarterly *Science Progress*, many books, and such publications as the annual *Report* of the Department of Scientific and Industrial Research, the annual progress reports on physics and applied chemistry published by the respective bodies (pages 157, 159), the articles which many journals publish in January of each year reviewing the progress made in particular fields of practice during the previous year, and the summaries which "*rapporteurs*" compile at congresses. The danger of relying too much on reviews, instead of digesting knowledge at first hand, is, of course, that the distribution of emphasis adopted by the reviewer may not correspond with what the reader's point of view requires; and this he cannot check.

The logical arrangement of the table is completed with F, the Full Text of the literature to which the foregoing items mark the approach, and finally G, the Reader's Own Notes or drafts of whatever he is writing, embodying the knowledge so conveyed to him. These are put after, and not before, the Full Text because printed literature does not in itself constitute knowledge: it is merely the means of creating knowledge in a mind which chooses to apply it for that purpose. On note-taking see page 227.

A warning should be given against the temptation to "short-circuit" F by using abstracts or reviews as if they were themselves the vehicles of knowledge. The proper use of these—be it repeated—is not to replace the originals but to tell the searcher which are the most promising references to examine, and to save him from wasting time on those unlikely to be of value.

As already stated, the table on pages 206–7 mentions only those series of abstracts which, whatever the languages of the original papers abstracted, are themselves printed in English. Were abstracts in other languages included it

would (at any rate before the war) have become several times as long. Some of the foreign series of abstracts (see note on page 205) used to be models of their kind. Mention may be made, for instance, of the excellent short abstracts (class C.4) in French, covering the world's technical press on several branches of engineering, on the backs of the advertisement pages of the respective sections of *Science et Industrie*, and of the five parallel issues of fortnightly batches of card abstracts (class C.5) relating to machine-tools, prime movers, welding, electrotechnics and regional planning and motor traffic respectively, issued by the Technische Hochschule in Berlin (see page 282). From 1936 to 1938 the cards on welding were translated into English and republished in London, but although much appreciated by subscribers the service could not, unfortunately, be made to cover its expenses.

Another venture before the war which most regrettably only lasted for a few months, and which would be worth reviving if it could be suitably financed, was a monthly publication from the United States which contained photographic reproductions of the " List of Contents " pages of a wide range of scientific and technical journals that had appeared during the previous month : a perfect example—by virtue of this up-to-dateness—of class A.1 in our table.

In regard to Russian journals see page 194.

THE CO-ORDINATION OF ABSTRACTING SERVICES

As a result of their haphazard and unco-ordinated development the abstracting publications, though numerous, are far from covering the whole international field of technical literature in a uniform way. A statistical survey carried out at the Science Library[1] showed that the aggregate

[1] S. C. Bradford : The extent to which scientific and technical literature is covered by present abstracting and indexing periodicals. *Rept. 14th Conf. ASLIB*, 1937, pp. 59–71.

number of references appearing annually in 300 scientific periodical bibliographies in all languages may be put at 750,000 or approximately the same as the total number of "good and very fair-class articles" (those of lower quality are excluded from the computation) in the world's technical press: but the fields covered by the various abstractors overlap to such an extent that about one-third of all the worth-while articles are indexed or abstracted several times over in different media while the remaining two-thirds are missed altogether. Another interesting discovery, which suggests the reason for this wasteful state of affairs, relates to the proportions in which the articles bearing on any given subject tend to be distributed between the more and the less specialised journals. As an example take the subject of Lubrication, on which it was found that (again considering only articles of good quality):

About 100 articles a year appear in	20 journals	to which it is a matter of constant and specialised interest.
Another 100 " " " " "	120 journals	commonly dealing with related or border-line subjects.
" 100 " " " " "	700 journals	devoted to less related subjects.
300	840	

Hence the compilers of an abstracting journal who wanted to make sure of noting all the 300 articles on lubrication would have to look through and pick their material from not merely 20 but 840 original journals, although in 120 of these the articles on that subject would be rare, and in 700 of them very rare. There is some evidence that the same law, whereby the numbers of journals in the three classes detailed above may be expressed as $1 : n : n^2$ with $n =$ about 5 or 6, holds good of other technical subjects also. The

remedy urged by Dr. Bradford is pre-indexing of the articles in accordance with the Universal Decimal Classification (see page 240) and a scheme of co-operation whereby all periodicals would be distributed for abstracting purposes according to their main subjects among appropriate agencies which would (1) abstract the articles falling within the specialised scope of each agency, and (2) " pass to a central clearing-house classified titles of articles not directly within their purview ", for redistribution of these to the most appropriate agency in each case. In this way each agency would receive notice of every article within its specialised field, without straining as at present to scrutinise the whole mass of literature in the vain endeavour to miss nothing.

Another—or a complementary—way of dividing up the field in co-operative abstracting is on the basis of language,[1] as has been done for physics and physical chemistry by the *Journal de Physique*, *Physikalische Berichte* and *Science Abstracts*, each of which have agreed to co-ordinate their work so as to cover the whole of their common field as completely as possible. More extensive schemes of the same kind have been suggested,[2] each country to abstract its own literature and the same abstracts to be made available in English, French, German and Italian.

The suggestion is sometimes made that the whole expensive business of compiling abstracts could be saved if every original journal were accompanied, on a loose leaf or on the back of an advertisement page, by abstracts of the articles therein (type B.4 or B.5 in our table), copies of the abstracts being also sent to a central organisation which would com-

[1] Prof. Gilbert Murray : The work of the Committee on Intellectual Co-operation of the League of Nations. *Rept. 1st Conf. ASLIB*, 1925, pp. 18–24.

[2] Sir Frederic L. Nathan : International abstracting and indexing of scientific and technical literature. *Rept. 8th Conf. ASLIB*, 1931, pp. 36–40.

bine them with those from other journals. The best person to make an abstract, it is urged,[1] is the writer of the original article, and in this way the abstract would in effect cost nothing. But 43 abstracting organisations, asked[2] in a questionnaire "If a paper includes an author's précis is this used in lieu of the abstract?", gave a definite "no" in 15 cases, answered "occasionally" or "rarely" in 6 cases, and in nearly all of the remaining 22 cases qualified their affirmative by the statement "if suitable". To another question "Is speed or accuracy the more important when both cannot be achieved?" the great majority replied in favour of accuracy.

The enquiry also revealed great differences in the methods of compiling and paying for abstracts, and these are borne out from other sources. In some cases, such as the various abstract publications of the D.S.I.R., and the *Engineering Index* in America, the work is done entirely by a full-time staff of technical experts and translators, but more often elsewhere[3] the journals to be abstracted are distributed by fulltime organisers and editors to qualified members of the society concerned who do the work in their leisure time and are paid at piece-rates.

Progress in the rationalisation of abstracting services on a national (and still more on an international) scale is not likely to be rapid, and the general conclusion drawn from the ASLIB enquiry on the subject was that "a policy of

[1] J. Lewkowitsch: The co-ordination of scientific literature. *Trans. 14th Conf. Int. Fedn. Documentn.*, 1938, reprinted in *Chemistry and Industry*, 24 Dec. 1938, pp. 1199–1205.

[2] Scientific and technical abstracting: a report on the ASLIB enquiry. *Rept. 9th Conf. ASLIB*, 1932, pp. 83–90.

[3] T. F. Burton: Abstracting. *Rept. 2nd Conf. ASLIB*, 1925 (publd. 1926), pp. 75–81. J. C. Philip: Efficiency with economy in chemical abstracting. *Rept. 10th Conf. ASLIB*, 1933, 74–7.

'collaboration at any price' . . . is as little worthy of recommendation as the 'specialist isolationist' attitude. Nevertheless . . . a useful background was revealed for generally implementing a policy of 'mutual assistance without interference'." (For the meaning of ASLIB see page 222.) Now in 1946 the matter is again debated.

Be this as it may, there is another aspect of the question worth considering. Since the compilation and publication of abstracts is not a commercially remunerative proposition the form in which the problem presents itself to the publishers of a particular series of abstracts is that of how to make the best use of a limited amount of money in the interests of the branch of science served in this way. Now it is suggested on page 204 that abstracts may be, and probably are, used by some subscribers mainly for current perusal (i.e. to look through month by month with a view to general awareness of what is going on in that branch of science) and by others mainly for back reference (i.e. as a means of assembling all the references that have appeared on a given topic when required). The relative importance of these two classes of use is not known but might be ascertained by enquiry.[1] If, as may well be the case, current perusal is found to be the more important use, then the present normal practice of publishing abstracts in printed pamphlet form may be justified. But if back reference is the more important use it might be preferable to save the large proportion of the total cost which is at present incurred for printing in order to cater primarily for "current

[1] The only clue in my possession is the fact kindly communicated to me by the editor of an agricultural publication, *Herbage Abstracts*, that 180 subscribers take its ordinary edition suitable for current perusal as against 20 who prefer the one-side-only edition (type D in our table) which can readily be turned into a card index for back reference.

perusers", and to spend what was so saved on extending the range of journals covered by the abstracts, the latter being filed either in typescript on cards—perhaps cards typed with reversed carbon imprint on the back with a view to reproduction by the Ormig process (see page 298), or in the form of addressing-machine stencils or reproducible photographically. A subscriber wishing for abstracts on any given topic—or who had given a standing order for them in advance—would be supplied, from the central bureau where they were kept, with photostats or Ormig-printed or addressing-machine-printed copies prepared from the master copies in the central index. With suitable organisation these could be posted to him within an hour or two of the receipt of his order by post card or telephone.

Some years before the war the cost of producing the British *Chemical Abstracts*, then a single publication, was given as—

£4,100	for abstracting and editing
2,500	for composition in type
1,500	for machining and binding
750	for paper
£9,850	total for 5,000 copies a year, each containing 2,500 pages of 1,000 words.

This publication has now become *British Abstracts* divided into the seven separate parts listed under Chemistry on page 206 and is produced by the Bureau of Abstracts, a joint undertaking of the six chemical and allied societies concerned. The Bureau has issued a 29-page pamphlet containing 127 rules for indexing and abstracting. It is staffed by three full-time workers and some part-time editors, and about half of the cost is stated to be recouped from sales.

In 1944 the Ministry of Production discussed engineering bibliography with representatives of the engineering institutions and it was suggested, though without effect since, that

co-ordination be undertaken by the D.S.I.R. with a lead from the Government, either through a national organisation to be set up on the lines of the British Standards Institution or perhaps by expanding the Bureau of Abstracts, above mentioned, to cover engineering also.[1]

"ASLIB" AND ITS FUNCTIONS

The Association of Special Libraries and Information Bureaux should be mentioned at this point in its own words as "a clearing-house for sources of information". Its membership, totalling in 1945 just over 500, includes both individuals and representatives of firms and corporate organisations which are users of technological and scientific information. On their behalf ASLIB, which now receives a Government grant administered by the Department of Scientific and Industrial Research, is concerned with everything covered by this and the next chapter, but the centre of gravity of its interests may, perhaps, be said to lie in what is described on page 238 as indexes of type (B). Its activities include a week-end conference, usually at either Oxford or Cambridge in September of each year, at which papers dealing with all aspects of organised information services are presented and discussed for subsequent publication in a *Report*. An enquiry bureau is maintained for members seeking sources of information and advice is given them on the organisation and classification of their own libraries and information bureaux; there is also an index for the location of unpublished documents and information. The *ASLIB Book List* is a quarterly publication giving a selection of recent scientific and technical books recommended by expert advisers, briefly annotated, classified under subjects,

[1] A. R. Stock: A survey of the present state of engineering bibliography. *Journ. of Documn.*, Dec. 1945, pp. 151–5.

and graded as to suitability for various purposes and classes of readers. A collective author and subject index to the nine volumes of the *Book List*, 1935–44, has been published. Another quarterly publication, begun in June 1945, is the *Journal of Documentation* containing articles " devoted to the recording, organisation and dissemination of specialised knowledge " not only in science and technology but also in the humanities, to which ASLIB has latterly extended its scope. *ASLIB Information* is a monthly broadsheet of several pages containing briefer notes, and book reviews, on matters of interest to members. In addition there is a quarterly *Bulletin* which includes a section in which the work described below is kept up to date.

The *ASLIB Directory* (" a guide to sources of specialised information in Great Britain and Ireland, published with the financial assistance of the Carnegie U.K. Trustees jointly by ASLIB and Oxford University Press, 1928 ") is a volume of about 450 pages divided into three sections. The first section contains, in alphabetical order, about 1,500 subject headings (scientific and other) under which there are references to over 2,000 sources of information. The original edition is now both out of print and to some extent out of date, but, pending its revision or replacement by something still better, it remains of sufficient value to those having access to it to warrant a brief description here. The *Directory* is arranged in three sections, of which the first contains :

Machine Tools

Books and periodicals on Machine Tools :
Coventry Public Libraries.

A section on—(members only) :
London : Institution of Civil Engineers.
London : Institution of Mechanical Engineers.

Non-confidential information given :
London : Machine Tool Trades Association.

A section on, including a large number of trade catalogues :
London : Patent Office Library.

Press.

London—
British Machine Tool Engineering.
Associated British Machine Tool Makers Ltd.

Implement and Machinery Review.
Westcott and Carpenter.

The second section of the *ASLIB Directory* is an alphabetical list of the towns and places mentioned in the first stating how and at what times information may be sought ; the third is a key to personal names attached to the various collections.

The ASLIB Register of Specialist Translators "exists to provide a service for those requiring translators or interpreters who not only possess expert linguistic qualifications, but are also intimately acquainted with one or more branches of specialised knowledge. . . . The dual qualification is made an indispensable condition of enrolment on the Register." In addition, a system is in operation for the pooling of translations already carried out on members' behalf.

Among the many contributions of ASLIB to the war effort which will remain of permanent value, apart from the extension and adaptation of services already described, have been assistance in the location and provision of periodicals from enemy and enemy-occupied countries as well as from Russia and from China ; the *War-Time Guides* to British sources of specialised information (on such subjects as Fuel, Agriculture, etc.), issued to supplement the

ASLIB Directory ; and, perhaps most momentous of all, the institution of the ASLIB Microfilm Service mentioned here on page 310.

The Library Association, concerned more with questions of professional general librarianship, is similarly connected with the International Federation of Library Associations which before the war held quinquennial conferences.

OTHER ASSOCIATIONS CONCERNED WITH BIBLIOGRAPHY

ASLIB is affiliated to the International Federation for Documentation (formerly the International Institute for Documentation), a body whose headquarters are at 6, Willem Wistenplein, The Hague, which used to hold annual conferences in different countries ; the last at Oxford in 1938. The papers presented at these are published as *Transactions.*

The International Federation for Documentation is represented in this country by the British Society for International Bibliography whose address is 28, Victoria Street, London, S.W.1. This body holds frequent meetings of its own, largely but not entirely devoted to furthering the cause of the Universal Decimal Classification, and publishes *Proceedings* to which a number of references have been given in several parts of this book. It practises what it preaches by printing the appropriate U.D.C. numbers at the beginning of each paper in these *Proceedings* ; for instance, the issue dated 18 April 1940 contains, at pages 13–26, a paper by Professor A. F. C. Pollard describing the Society itself, which is indexed as 061·22 : 01. Similarly, the paper on Standardisation cited in this book at [162·1] bears the U.D.C. index number 62(083·7)(061·5).

ASLIB'S counterpart in the United States is entitled the Special Libraries Association which has its headquarters

at New York. The latter is not to be confused with The Library Association in this country which is the governing body for professional general librarianship and is connected with the International Federation of Library Associations. Until the war the latter organised an international conference every five years.

LIBRARIES

Most establishments in which research is done, and societies like those mentioned in Chapter Four of this book, maintain " special " libraries which perform additional functions as discussed here on page 256. ASLIB, during the war, has organised emergency courses of training in this type of librarianship, through which some 150 students have passed. Short textbooks on the subject are J. L. Thornton : *Special Library Methods* (London : Grafton, 1940), and J. E. Wright : *Manual of Special Library Technique* (London : ASLIB, 1945). Guidance to named libraries of this type may be found in the *ASLIB Directory* and in H. P. Spratt : *Libraries for Scientific Research in Europe and America* (London : Grafton, 1936), which also deals with the central libraries such as those mentioned below.

The reader who has the use of a special library will normally find it more convenient, so far as its scope extends, than the larger central libraries ; for one thing, it is a great advantage to be allowed free access to the shelves and be able to tell at a glance whether any given reference is in fact the one he needs instead of having to fill in a demand slip and wait several minutes—if not longer—for the book to be brought by an attendant. But since the resources of a private or special library are necessarily limited to those books, journals and abstracts which belong to its immediate field of interest, it follows as a corollary to what was said

here a few sections back that among the most important functions of the librarian in charge of such a library is that of maintaining contact with more general libraries and of knowing how to draw upon, or direct readers to, the world's technical literature as a whole. In this country the two largest collections of such literature, both of them supported from public funds, are those described below.

The Patent Office Library in Chancery Lane, London, W.C.2., does not lend literature outside but is open to the public without charge or formality daily, except Sundays and holidays, from 10 a.m. to 9 p.m.; the late closing hour is a special boon to those who do research in their spare time, and another important point is that (except as regards a small proportion of journals) direct access is allowed to the shelves. One of the main features is, of course, the collection of patent specifications, both British (complete since the year 1449) and foreign, among which searches can be made with the aid of an elaborate system of indexes and abridgments; copies of British patent specifications may also be purchased at 1*s*. each. In addition to the patents there are some 275,000 bound books, and files of 3,500 technical periodicals in all languages, as well as indexes, abstracts, dictionaries and works of reference.

The Science Museum Library in South Kensington is open on weekdays from 10 a.m. to 6 p.m. It contains about 300,000 volumes and the accessions number 12,500 volumes a year, 9,500 of these being presentations and the remainder purchased with an annual grant from the Government of £3,500. These totals include the files of some 9,000 scientific periodicals currently received. All these books and journals are not only available for consultation in the reading-room of the library itself but may be borrowed outside on application through the librarians of any of

about 450 institutions and firms which are admitted to this privilege on accepting responsibility for loss or damage, or through the National Central Library mentioned below. In 1938, 27,000 readers visited the library and there were also 27,000 outside loans. In 1944, owing to war conditions, the number of visitors dropped to 16,000, whilst the number of loans rose to 39,000. The bibliographical and indexing activities carried on by the staff of the Science Library are especially notable and are described in the next chapter, page 238.

England and Wales are now covered by nine Regional Library Systems whereby 506 urban, county, university and special libraries are linked up and lend each other books not available locally. By applying to the nearest of these local libraries it is possible in this way to draw upon—

6,800,000	books	in	university libraries.
10,398,000	,,	,,	urban and county libraries in the regional systems.
4,480,000	,,	,,	outlier libraries which are outside the regional systems but lend books through the National Central Library, London (this total includes about 35,000 sets of periodicals).
88,760	,,	,,	the National Central Library's own stock.
21,766,760			

in addition, where necessary, to loans from foreign countries. The " outlier libraries ", 162 in number, are mainly special libraries, including for instance those of most of the trade research associations listed on pages 172–3, and, what is especially important here—including the Science Museum Library whose vast resources thus become accessible to everyone.

The totals given above are not all scientific books but cover every subject. Books which are available at the local library, books which are in print costing less than eight shillings,

works of fiction and the set textbooks required for examinations, cannot be supplied through the National Central Library, but every endeavour is made to provide any other type of book. The service is free except for postal charges, income being derived from the Carnegie United Kingdom Trust, other foundations, a grant from H.M. Treasury, subscriptions from library authorities, adult class organisations for which books are provided, and individual subscribers. There is need for an endowment fund.

COPIES FOR RETENTION

Assuming some book or journal has been recognised as potentially useful it must obviously, if its value is to be realised, remain in the hands of a reader long enough to let him assimilate its contents and take any necessary notes, and perhaps to juxtapose and compare it with other papers which may not be immediately available. Circumstances may in fact be such that the period of loan from a central library is not long enough, or such as to make it desirable or essential for the individual to keep a copy in his permanent and immediate possession.

When this is true of a book the obvious course is to order a copy through a bookseller, and it is worth while for an organisation employing responsible research workers to allow them considerable discretion in incurring expenditure for that purpose. In the case of an article in a journal at least three possibilities are open :

(1) The simplest and sometimes the cheapest method may be to order a back number from the publishers, or in the case of a paper presented at an institution to ask the secretary for a spare pre-print or reprint if available.

(2) Many duplicating offices and engineers' photo-printers will make photostat copies (see page 304) of the required

pages of any volume submitted to them. Photographic copies of any of the material in the Patent Office Library—which, as explained two pages back, includes practically any engineering or industrial journal likely to be wanted—can be obtained on application, the charge being *6d.* per foolscap sheet post free, prepaid or debitable to a deposit account. The *Engineering Index* in New York, whose address is given at [209·1], provides a similar service. See also page 309 regarding microfilm copies.

(3) The method of the future is probably that of microphotography, regarding which see page 305.

NOTE-TAKING

The notes which a researcher or a student makes on his reading, in listening to a lecture or in order to summarise a technical conversation deserve to be recognised as an important and peculiar class of document which differs in its primary purpose from any other, and the rationale of which demands consideration.

The object of making one's own notes for one's own use is psychological. It may be worth while to do so even though the original source of the knowledge noted remains accessible or even though an adequate summary or abstract prepared by someone else is already available ; because note-taking is an aid—often an indispensable aid—to mental digestion. Perhaps the explanation of this is that the co-ordinated muscular movements involved in writing serve to reinforce the impression which the mind receives from the perception of the written or spoken words, a perception which in the absence of some such reinforcement tends rapidly to become dulled. If the reader questions this let him compare how much he can remember now of (*a*) the contents of yesterday's newspaper which he read without

doing any writing, and (*b*) the wording of the last letter he himself wrote.

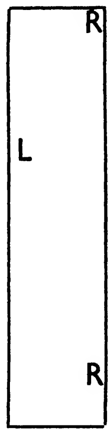
It is for this reason that in the table on page 205 the "reader's own notes" and not the "original text" has been represented as the final step in the realisation of knowledge. One may see or hear words passively and uselessly without unpacking them and releasing their content of ideas into one's mind. To unpack them completely and in due order one must revolve them in one's mind till thought or action ensues, and the best way of compelling this is to write notes.

The optimum length and form of notes is, however, a difficult problem in individual pyschology. Too full notes are no more useful than no notes at all; a shorthand reporter straining to catch and record every syllable of a lengthy discourse, or a copying typist whose pride lies in literal accuracy, is barred by the very intensity of that effort from mentally assimilating the content of what is recorded. The best compromise is to write notes in the form of a précis; whoever would study to advantage needs to ascertain what length of précis suits his particular case and to discipline himself accordingly.

The choice of method in reading and note-taking is essentially a personal matter wherein standardisation would be out of place: but method there should be. My own habit, for what it may be worth, is first to skim rapidly through the book inserting slips of paper to mark the passages which appear *prima facie* worthy of attention (the example here illustrated full size indicates that a point which appeared interesting was noticed at about one-third the distance down the left-hand page against which the marker was inserted, and two others at the top and near the bottom of the right-hand page) and then to go over these again

more thoroughly, making notes on to cards or pieces of stiff paper from an 8 inch by 5 inch correspondence pad which can afterwards be added to the index-file of personally collected data described here on page 261. The notes are written in a mixture of shorthand and much-abbreviated longhand and vary in fullness from occasional memory-aiding catchwords to long verbatim extracts. Given suitable apparatus, a quicker way—but would it be so effective as a digestive aid?—would be to photograph the pages of interest, make 8 inch by 5 inch prints of them and afterwards to underline in these the important passages.

Numerical data, especially, call for something more active than mere contemplation, if mental nutriment is to be derived from them. Figures acquire useful significance only when the reader himself initiates with them some definite process of thought. What this process is matters little: it may take the form of re-tabulating the figures in a different arrangement from the original, of juxtaposing them with comparable figures from another source, of trying to calculate something else from them with the slide rule, or of plotting them in a graph.



An alternative to inserting markers, as explained above, between the pages that appear to contain points of interest is to jot down the page numbers followed by a decimal to indicate roughly how many tenths of the way down the page the point in question occurs. For instance, I should call the line which the reader is now perusing 229·9, as it is roughly ·9 of the way down page 229.

The thing to be avoided at all costs is the marking of other people's books.

SUMMARY OF ADVICE ON THE USE OF PUBLICATIONS

Some readers may find it helpful to have what is here advised presented in the form of a series of suggestions :

(1) For the sake of the background and stimulus they afford, make a habit of looking through several journals fairly regularly as they come out, including, say, one or two of a broad professional and cultural character like *The Engineer*, *Engineering* and *Nature* as well as one or two relating to your more specialised interests and one or two foreign journals. Turn over their pages, not omitting the advertisements ; read the editorial articles and whatever other contents arouse your interest ; glance at the book reviews—but remember, with Bacon,[1] that " to spend too much time in studies "—in the sense of aimless reading—" is sloth ".

(2) When, however, your need is for specific information as distinct from long-term education, remember that the most useful information for whatever your particular purpose may be is more likely to have appeared somewhere among the 25,000 series of technical journals and 14,000 books newly published each year which you have not seen than in the odd dozen which you have seen and can remember.

(3) If, this being so, it is important for you to be kept systematically aware of developments in some particular field of science, become a regular reader of the most appropriate of the abstract publications relating to that subject as listed on pages 206–7 or the foreign ones referred to in the note, recording any references so found which appear of permanent interest. If no suitable abstract publication exists covering the speciality in question the next best course is to pick out the most promising of the actual journals and

[1] Essay " Of Studies ", the whole of which is apposite here.

make your own abstracts or notes from these (but remember that in this way you can cover only a minute portion of the ground: see page 214).

(4) If you frequently need to keep abstracts for future reference it is preferable—though not, of course, always feasible—to take them from those types of publication which are classifiable in columns 4 or 5 of the table, whereby the necessity for copying is avoided and the abstracts themselves can readily be formed into a card index of the kind described on page 238 in the next chapter as an index of type (C).

(5) If, however, you have access to an index of type (B) covering the desired subject matter it may not be worth while duplicating this on your own account—unless, like the present writer, you regard the personal indexing of collected material, interleaved with your own notes, as an aid to sorting out your ideas, and value the stimulus afforded you by being reminded each time you use the index of what is already in it.

(6) For the purpose of a "literature search"—that is to say, for the *ad hoc* assembling of all existing data on some given topic—use, if available, an index of types (B) or (C). Failing this refer to back numbers of the *Engineering Index* (in any good technical library) or of other abstract publications listed as far as possible to the right in the table on page 205. Ascertain, also, from the *ASLIB Directory* (see page 220) whether there is any special library, or by using the index of the present book whether there is any society or other organisation which specialises in the subject you wish to study and may be able to help you. (On how to conduct a literature search see also 203.)

(7) If you wish your search to be exhaustive do not, for the reason stated in (2) above, rely on the indexes in the

back volumes of a few individual journals chosen by chance, but use an index in which as many journals as possible are unified as described above.

(8) Do not regard abstracts, reviews and references as ends in themselves but only as time-savers to tell you which of the original publications probably are not worth turning up. An author must be presumed, if competent, to have expressed what he has to say in the shortest form consistent with completeness, and it is not fair to either the author or yourself to read this only in an abridgment made by someone else.

(9) Nor need any difficulty arise in referring to original publications. In Great Britain practically the whole of the world's technical literature is accessible to everyone and it is even possible, through the channels mentioned in this chapter (page 225), to borrow books and journals from the Science Museum Library for use in one's own office or home, free of charge.

(10) It is worth while for a company or association which spends thousands of pounds a year on staff salaries to spend also an occasional few shillings on acquiring printed copies, photostats or microphotographs of publications for permanent retention so that full value can be extracted from the latter instead of having to return them prematurely to a lending library.

(11) It is worth their while, also, to spend an occasional few pounds on having translations made by technically qualified linguists, so as to utilise the most valuable available knowledge on any given subject regardless of the language in which it is expressed (see page 221).

(12) Time spent on local indexing is time saved in searching. Individual circumstance must decide whether it is worth while to index so exhaustively that any item that may

become of interest will automatically be thrown up, or, at the other extreme, to index nothing but rely on *ad hoc* searches when occasion arises, or to follow any intermediate course ; the criterion being that—subject to weighting in accordance with the value of the information—the *total* number of man-hours expended over a period of years on indexing and filing on the one hand, searching and note-taking on the other, should be a minimum. To put the matter in another way, organised bibliography is a form of insurance against ignorance, and whether the premium is commensurate with the risk is for the insurer to decide.

CHAPTER SEVEN

THE SORTING AND INTEGRATING OF FACTS AND IDEAS

INTRODUCTION

THE object of research, the end point of all the processes mentioned in this book, is the production of knowledge or, in other words, of systems of ideas.

Consider, now, the process whereby an idea is given birth—whether it be the simple commercial example " a market exists for a commodity having certain characteristics ; we make something which has those characteristics : hence (if the price is right) there may be an outlet for our product in that market ", or anything between this and the most recondite philosophic theorising.

It will be recognised, on analysis, that an " idea " is the outcome of the simultaneous presence of two or more separate pre-existing items of knowledge in a single human mind sufficiently informed to see each item against its background and sufficiently alert to discern a useful relationship between them. The conditioning of that background and that alertness is the business of the educator and the psychologist, but the presentation of items of knowledge in such a way as to increase the likelihood of the simultaneous presence, in one suitably attuned mind, of such items as are likely to be fruitful when brought into juxtaposition, is a matter which can be influenced by the efficiency of bibliographical machinery such as card indexing now to be described.

KINDS OF INDEXING

In broadly applying the term "indexing" to this machinery it is important to recognise certain distinctions.

In the first place, an index may take any of several different physical forms; it may be printed as a continuous list like the index appended to a book or it may be in the form of a card index, or of a loose-leaf register. The latter two are the only ways of maintaining an "interminable" index, that is to say an index to which new items are continually being added and are required to fit into their proper places among those already present. The only advantage of a loose-leaf book over cards in a cabinet is greater portability, but a book is not so quick for inserting new items.

Secondly, there is a difference between enumerating the names of things in alphabetical order and classifying the things themselves on a scientific plan. Thus in an alphabetical index arranged like a dictionary the different parts of a motor-car such as the Brake-lever, Carburettor, Commutator, Dynamo, Gearbox, Steering-gear, etc., would appear in that order in different parts of the index mixed up with items having nothing to do with motor-cars; whereas in a classified scheme of arrangement they would be collected together, under the heading of "motor-car", in some sequence that depended on their physical and functional relationships. The alphabetical arrangement may seem the more convenient at first sight but is apt to cause difficulties through the existence of synonyms; thus an indexer may apply the word "accumulator" to an item which someone else will look for under "secondary cell", "cell, secondary" or "storage battery". Moreover, an alphabetical arrangement holds good for one language only; even the differences between English and American usage may upset it, as, for

instance, in reference to railways, where the Americans substitute tie for sleeper, splice-plate for fishplate, towerman for signalman, depot for station, and so on. In indexing literature in a foreign language, especially, these difficulties become formidable and lend weight to the arguments for abandoning alphabetical arrangement in favour of a system of classification—described later—in which every possible concept is allotted a number which holds good regardless of the language in which it happens to be talked about.

Thirdly, we must distinguish between what may be called cataloguing, analytical indexing and index-filing, each appropriate to a different purpose as follows :

(*a*) The entries in a *catalogue* are the titles, authors or main subjects of whole books or other documents each of which is treated as a unit, each entry followed by a " shelf mark " or " call number " which is the key to the location of the book or document in question—these being shelved or filed in any convenient way suggested by their physical characteristics, as, for instance, books according to size and under main subjects and authors, periodicals in order of date, reports according to origin, correspondence in folders marked with the names of correspondents, and so on.

(*b*) The entries in an *analytical index* are indications of the subject matter not of books and documents considered as wholes but of the individual pieces of information contained therein, followed not only by the appropriate shelf mark but by a reference to the page number where the particular item is to be found. Analytical indexing, therefore, involves reading or at least scanning the books ; not merely noting their titles and bibliographical descriptions.

(*c*) If the knowledge-bearing documents are not books but are themselves separate cards, or are cuttings or loose

sheets of paper which can be pasted on to or treated like cards, they may themselves be arranged in alphabetical or other logical sequence and there will then be no need for a separate index. Such an arrangement will here be designated as *index-filing*. It is particularly useful as a method of keeping abstracts.

Finally, one may distinguish different objectives in indexing, corresponding to different degrees of completeness with which the literature has to be covered, different degrees to which it is desirable to centralise the work—and different methods. Just as it is possible to turn screws with a chisel but a good workman does not do so, it is possible but inexpedient to apply the same systems of indexing to all purposes. In order to illustrate this fact it is proposed, in the remaining sections of this chapter, to describe three actual systems of indexing which are in fact found to be appropriate in the following respective settings; the purposes distinguished as (A), (B) and (C) below being typically—but not necessarily—associated with the kinds of index called (*a*), (*b*) and (*c*) above:

(A) Indexing *in a central library* with the object of warehousing and cataloguing as much as possible of the world's technical literature as a whole, not in anyone's particular interest but for the good of all. Here the governing considerations must be comprehensiveness and impartiality. So far as possible *every* assembly of knowledge contained in the unceasing flood of publications must be noted and its location recorded, even though at the time of doing so it is impossible to tell whether that item will ever be of use to anyone, or to whom or in what way it will be of use. There being no personal link between indexer and possible future user, the method of indexing must be so logical and so standardised that anyone seeking knowledge of a specified kind has only

to follow the rules in order to be sure of exactly where the indexer will have put it if it exists.

(B) Indexing *in a special library or information bureau* as a means whereby library staff, who should be in close touch with the actual research staff but are not the same persons, can sift out from current and past publications the particular kinds of references desired. The function to be fulfilled may be described as "controlled selectiveness".

(C) Index-filing *by an individual* who requires to keep at his finger-tips, for constant reference, the data he uses as a background for his day-to-day thoughts on technical matters, or is engaged in putting together to create new knowledge. Here, be it noticed, the ideal is not the passive storage of as much potentially relevant material as possible but something quite different: the active utilisation of personally selected material. The index-file serves as a kind of hotbed in which to force the growth of the user's own ideas. Hence the system must above all be flexible so as to stimulate and not hinder originality of thought, and wherever possible the actual data, not merely the indication of where they are to be found, should be placed literally at his finger-tips.

On the indexing of personal contacts see [32·1].

INDEXING IN THE SCIENCE MUSEUM LIBRARY

The great library at South Kensington may, as already suggested on page 224, be regarded as the keystone of scientific and technical bibliography in this country, and the subject indexes maintained there provide the best possible setting in which to outline the characteristics, possibilities, advantages and economies—at any rate in the roles it is there called upon to play—of what is named the Universal Decimal Classification of Knowledge and is described in the next section.

The various card indexes comprise four separate divisions which will be discussed in order of their interest to the public:

(i) The *Author Index of Books Published* is a cumulative catalogue of scientific and technical books published throughout the world since 1931, now totalling over 50,000 cards to which about 150 are added weekly. These are compiled from various national book lists and give details as to price, date, place of publication, etc., needed when books not in the library are requisitioned by readers; they serve also as a basis for the selective acquisition of new books by purchase or otherwise.

As soon as a book is actually acquired by the library a reference to it is included in the "catalogue" portion of the *Weekly Bibliography of Pure and Applied Science*, a mimeographed document available to subscribers. A few copies of this are cut up and the items mounted on cards which are added to the two following card catalogues:

(ii) The *Author Catalogue* of about 250,000 cards arranged alphabetically, containing one reference to every separate work in the library, under its author or publishing institution. Herein a periodical will have only one entry, as a whole, unless it has been merged with another or its title has been changed.

(iii) The *Subject Catalogue* to the same works as (ii) and again containing about 250,000 cards, arranged numerically under subjects in accordance with the Universal Decimal Classification of the latter.

Apart from these there is—

(iv) The *Subject Matter Index to Periodicals*, which is an analytical index to the contents of individual papers and articles appearing all over the world in many languages, now amounting to some 2,500,000 cards to which additions are

being made at the rate of about 150,000 a year. This enterprise is rendered possible by that international co-operative working to which the Universal Decimal Classification provides the key as described in the next section, the index being formed mainly by cutting out and mounting on cards abstracts or references compiled by various international sources and already bearing the appropriate U.D.C. class numbers. Such cards are supplemented by others bearing the references in the " analytical " portion of the Science Library *Weekly Bibliography* aforementioned, the staff themselves indexing decimally for this purpose the contents of about 200 British periodicals which relate to general science.

These resources are further utilised by the Library staff for the compilation of periodical *Current Reference Lists* on certain subjects (in 1939 these were Experiment Tank Work, Applied Geophysics, and Lubrication), and similarly for *ad hoc* lists of references in response to specific enquiries to the number of 100–120 every year (two-thirds of them on applied sciences) containing some 3,000 references in all. In terms of the Key Diagram on page 205 these lists are of type A.4, and they bear, of course, the U.D.C. numbers against each item. This service is free of charge to users within the British Empire or at the rate of 2*d.* per reference (minimum 5*s.*) outside.

The material stored in the Science Museum Library also includes many bibliographies which have been compiled elsewhere, estimated to contain a total of over 40,000,000 references to scientific and technical literature.

THE UNIVERSAL DECIMAL CLASSIFICATION

A system for the designation of subjects of knowledge by means of decimal numbers on a standardised plan, any desired degree of subdivision of a subject being attainable by

extending the number of decimal places, was originated in 1876 by Melvil Dewey in the United States and is now used by well over 90 per cent of the libraries in that country. The main tables of the Dewey system[1] contain about 11,000 divisions and subdivisions of subjects each with its allotted number; those of its European derivative, the Universal Decimal Classification,[2] contain over 100,000 differing from Dewey only in the more minute subdivisions and in the fact that regular machinery[3] exists for the introduction from time to time of approved modifications and extensions while preserving the international uniformity which is one of the chief merits of the system. The Universal Decimal Classification is sometimes known as the Brussels system by reason of its association with the vast index of 14,000,000 cards in the Palais Mondial there.

It is the aim of those who advocate the Universal Decimal Classification that eventually no book, paper, article, abstract or reference will be published without the appropriate subject class number or numbers ready printed on it, thus enabling it to be dropped into place at once in any collection so classified without the need for local indexing or perusal or, indeed, for any knowledge of the language of the original. Ten years ago it was estimated that some 10,000 organisations in 42 countries were in fact using the

[1] M. Dewey: *Decimal Clasification and Relativ Index.* Vol. 1: Tables. (New York: Forest Pres, 12th edn., 1927.) Uzers of this book have to overcome their prejudis against the chanjes in speling favored by the author for which he claims the support of filologic associations and prominent skolars. But these do not affect the utility of the work.

[2] *Classification Décimale Universelle* (Brussels: 2nd edn., 1927–33, 4 vols.) and explanatory *Exposé.*

[3] The controlling body is a commission associated but not identical with the International Federation for Documentation at 6, Willem Witsenplein, The Hague, Holland. It is represented in this country by the British Society for International Bibliography.

Universal Decimal Classification for various purposes and that altogether over 1,500,000 documents, bibliographies and individual articles in periodicals had been printed bearing its class marks. The number of scientific journals sent out ready indexed in this way is stated to be over 100, including 28 in Great Britain and smaller totals in Germany, France, Belgium, Switzerland and other countries.

The full tables of the classification, covering all subjects whatever, are at present available only in French, but before the war the Science Museum Library, supported by a Joint Committee of ASLIB and the British Society for International Bibliography, had undertaken and partly completed the republication in English of certain classes relating to science and technology. Stocks of these publications were later destroyed by enemy action, but meanwhile, in 1940, the Joint Committee had adopted a proposal that the English edition should be completed by the British Standards Institution. This work is now in progress and the following sections are now available from that source as parts of British Standard Specification 1,000, at the prices shown:

Vol. 1, Part 1—	General Introduction ; Auxiliary Tables ; Class O Generalities.		Price 7*s.* 6*d.*
Vol. 2, Part 1—	Class 50	General Works on Pure Science.	
	Class 51	Mathematics.	
	Class 52	Astronomy, Geodesy.	
	Class 53	Physics.	Price 10*s.*
Vol. 2, Part 2—	Class 54	Chemistry.	Price 10*s.*
Vol. 2, Part 3—	Class 55	Geology, Geophysics.	
	Class 56	Palaeontology.	
	Class 57	Biology.	
	Class 58	Botany.	
	Class 59	Zoology.	Price 10*s.*

In addition, preliminary drafts of the following have been

issued by the British Standards Institution under the code numbers shown (which bear no relation to the U.D.C. numbers) :

CG(DOM)8734—Class 611 Anatomy. Price 2*s.*
CG(DOM)9167—Classes 613–614 Hygiene in general and Public Hygiene. Price 2*s.*
CG(DOM)4882—Class 620 Testing of Materials, Power Stations, Economics of Energy. Price 1*s.*
CG(DOM)4883—Class 621 Special Analytical Subdivisions ; Class 621·1 Production, Distribution and Utilisation of Steam ; Class 621·2 Distribution and Utilisation. Price 2*s.* 6*d.*
CG(DOM)3091—Class 621·3 Electrical Engineering. Price 2*s.* 6*d.*
CG(DOM)5282—Class 621·4 Heat Engines (other than Steam Engines. Price 1*s.*
CG(DOM)5338—Class 621·5 Production, Distribution and Utilisation of Pneumatic Energy. Refrigeration. Price [illegible]*s.*
CG(DOM)5430—Class 621·6 Machines to set Fluids in Motion, to Raise, Store and Project Liquids and Gases. Price 1*s.*
CG(DOM)6336—Class 621·7 Factories, Workshops, Manufacturing Processes. Price 2*s.* 6*d.*
CG(DOM)7116—Class 621·8 Power Transmission, Driving Gear, Cranes, Lubrication. Price 2*s.*
CG(DOM)8174—Class 621·9 Machine Tools, Machining. Price 2*s.*
CG(DOM)2235—Class 629·13 Aircraft Engineering. Price 1*s.*
CG(DOM)7708—Class 666 Glass and Ceramic Industries. Price 2*s.*

Furthermore, the sections relating to the particular branches in which they are concerned have also been published in English by several institutions, such as the Optical Society,[1] which have adopted the system for their own use, and when this is done the opportunity is taken to submit proposals to the governing body for any improve-

[1] A. F. C. Pollard : *The Decimal Classification of the I.I.B.* (Cambridge University Press, 1926) is described as " a translation of the outlines of the Classification Décimale followed by a full translation of the sections on optical subjects, with an admirable introduction explaining fully the relation marks ".

ments in detail which the review carried out in the light of special knowledge of a particular science may suggest.

In a library where the indexing is done in accordance with the Universal Decimal Classification it is convenient to provide a key in the form of a separate collection of cards arranged alphabetically.[1] A searcher proceeds by finding out from this the number or numbers which relate to the topics on which he requires information, and then turning up these in the index proper.

The basis of the Universal Decimal Classification, as of the Dewey system, is that the whole of knowledge is considered to be represented by unity and is divided firstly into ten parts represented by the first digit after a decimal point as follows :

·0 General works (such as encyclopædias).
·1 Philosophy.
·2 Religion.
·3 Social Sciences, Law.
·4 Philology.
·5 Pure Science.
·6 Applied Science.
·7 Fine Art.
·8 Literature.
·9 History, Geography.

Each of these main classes is further subdivided by the addition of another decimal place ; for example, class ·6 Applied Science is subdivided as follows :

·60 Applied Science in general.
·61 Medicine, Anatomy, Physiology.
·62 Engineering.

[1] Rules for doing this are appended to the paper by A. F. C. Pollard and S. C. Bradford : The inadequacy of the alphabetical subject index. *Rept. 7th Conf. ASLIB*, 1930.

·63 Agriculture.
·64 Domestic Economy.
·65 Technique of Commerce, Communication and Transport.
·66 Chemical Technology.
·67 Manufactures.
·68 Industries, Trades.
·69 Construction.

Each of these sub-classes is further subdivided giving rise to a third decimal place, and the process of subdivision is repeated as often as the analysis of the subject matter requires. For the sake of legibility the figures are grouped in threes separated by decimal points, but the point at the beginning is usually omitted and "taken as read". The following, for instance, are further subdivisions of ·62 Engineering:

620 Engineering in general.
621 Mechanical engineering.
621·2 Hydraulic power.
621·24 Hydraulic turbines.
621·242 Hydraulic reaction turbines.
621·242·5 Limited reaction turbines.

In this way every elemental concept has its allotted number which means that, and that only, in the classification; the number representing any subdivision of any class has a definite place in the numerical sequence, and no matter how extended the subdivisions of any one class may become the order of the decimal numbers representing the two classes on either side of it remains undisturbed.

To illustrate the advantages of systematic classification over alphabetical indexing by catchwords, Dr. Bradford[1]

[1] S. C. Bradford: The international indexing of scientific and technical papers, *Engineering*, 3 Feb. 1933. This forms a useful outline of the Universal Decimal Classification as applied at the Science Museum Library. The international organisation of bibliography, *Engineering*, 15 Oct. 1937, p. 441, is the title of a shorter article by the same author.

selects the following example of an entry from the *Engineering Index*, a publication which is arranged alphabetically :

> Oil Well drilling—rotary. Preparation of hard alloys for oil well drilling.

Actually the paper indexed under this heading deals with the manufacture and properties of iron-chromium and tungsten alloys, and if a description of its subject matter were written in the order of the importance of the terms it would become : " Iron-chromium and Tungsten alloys for Bits for Boring-machines for Wells for Oil ". Thus the cataloguer, working from the title and not from the contents of the paper, has effectively hidden the reference under an arbitrary subdivision of a heading which begins with the least important word in the title—and this although there are other papers appearing in the *Index* under Chromium-iron alloys, Tungsten alloys, Alloys, Boring-machines and Drilling-machines. But using the Decimal Classification, complex ideas are represented by combinations, separated by colons, of the numbers which stand for their simpler constituents and the paper on chromium steels and tungsten alloys for bits for shaft-sinking machines would be classified as follows :

669·144·3 : 622·24·051
669·275 : 622·24·051

in which the two 669 numbers represent respectively chromium steels and tungsten alloys and the two 622 numbers represent bits for shaft-sinking machines.

A further example is afforded by the following short abstract :

66·089·4 : 628·511·4

H. J. Bush : Trans. Inst. Chemical Engrs., 1938, 2, 18. The use of electrical precipitation apparatus for removing mist and dust from industrial gases is reviewed and discussed.

The longer abstract illustrated in Fig. 8, page 274, would be indexed by the Universal Decimal Classification as follows :

621·892 : 621·436
621·892 : 621·431·74

The following more extended illustration of the variety of ideas that can be expressed by ringing the changes on either side of a colon is taken from a paper on documentation in the laboratories of J. P. Lyons & Co., Ltd. [248·1] :

663·674	Ice cream : general
663·674 : 532·13	Ice cream : viscosity
: 545	Ice cream : quantitative analysis
: 547·454	Ice cream : sugars, "sandiness"
: 576·8	Ice cream : bacteriology
: 613·262	Fruit for use in ice cream
: 613·262·75	Strawberry ice cream
: 614·31	Ice cream control ; legal standards
: 614·31(416)	Ice cream control ; legal standards (Northern Ireland)
: 621	Ice cream plant
: 621·56	Freezing ice cream
: 637·145	Milk powder for use in ice cream
: 637·148	Cream for use in ice cream
: 637·2	Butter for use in ice cream
: 66·063·6	Ice cream : homogenization
: 663·91	Chocolate ice cream
: 664·8·036·3	Ice cream : pasteurization
: 668·317	Ice cream stabilizers (gelatin, etc.)

If, as in these examples, the U.D.C. reference consists of several related numbers, as many identical cards would be made as there are numbers, and one such card would be filed under each number underlined in turn, thus ensuring that the reference in question will be found with equal directness under any of the headings where it may be relevant.

The colon is only one of several recognised signs and devices whereby numbers standing for elemental ideas may be connected up to represent more complex notions. Any of the following may be employed either singly or in combination, the order in which they are mentioned here being that in which the various signs affect the sequence of filing :

Sign.	*Meaning.*	*Example.*	
+	additional subject	631·312 + 631·331	Ploughs and sowers.
/	extension of same subject	631·312/313	Ploughs and harrows.
	(principal number)	631·312	Ploughs.
:	relationship of different subjects	631·312 : 631·411·3	Ploughs for clay ground
=	language	631·312 = 3	Documents on ploughs in German.
(O..)	type of publication	631·312(021)	Manual on ploughs.
(..)	place	631·312(42)	Ploughs in England.
" .. "	date	631·312" 17 "	Ploughs in 18th century.
A/Z	proper names	631·312 Lanz	Lanz type ploughs.
-	analysis of the subject	631·312–78	Safety devices on ploughs.

These elaborations are optional and are used mainly in analytical as distinct from cataloguic indexing. On the other hand there is no need for every user to employ the fully developed tables intended for specialists and experts, and for many purposes an abridged system consisting only of the major groups is all that is needed.

" The U.D.C."—claims one of its advocates [1]—" is par-

[1] M. Shaw : Documentation in an industrial laboratory. *Proc. Brit. Soc. for Intl. Bibliog.*, 1942, Vol. IV, pp. 1–11. The *Proceedings* of this Society include papers, from time to time, on applications and proposed extensions of the U.D.C. in special fields ; e.g., recently, for plastics and for building.

ticularly useful for dealing with the vague type of enquirer who wants to trace an article perhaps read two or three years ago and has forgotten the author, title, the journal in which it appeared, and even the general trend of the article, but remembers that one section of it, for example, was devoted to the effect of sonic vibrations on bacteria. The enquirer looks agreeably surprised when the reference is found immediately under 576·809·512 (the effect of vibrations on bacteria)."

On the other hand the U.D.C. whilst certainly the most thorough attempt yet made to attain the objective implied by its title, is by no means secure against criticisms on the grounds of illogicalities, ambiguities and difficulties in use which even the sectional revisions undertaken from time to time under its international constitution can never completely overcome. The necessity to divide each successive stage of sub-classification into exactly 10 parts (of which one is zero or " general ") crowds some subjects and brings others which are incongruous into juxtaposition : thus Mineralogy is a subdivision of Chemistry instead of being placed as a branch of Geology ; Chemical Industry has its allotted place but Physical Industry (such as wireless) has none except as a branch of Engineering [216·1]. But the fact that the same material is sometimes classified over again under several headings appertaining to different branches of science is not necessarily a disadvantage.

Apart altogether from indexing, the Universal Decimal Classification provides an admirable method for marking books to regulate the sequence of their arrangement on the shelves : it is better for this purpose than writing the number of the shelf in each book as it avoids having to re-mark the books whenever the overcrowding of a particular shelf necessitates moving them to another. On this account the

Decimal Classification is frequently employed for the cataloguing and shelving of books [1] even in libraries which do not use it for analytical indexing.

THE KAISER SYSTEM

The system of analytical indexing now about to be described was first applied to technical subject matter some 30 years ago by its inventor working in the research organisation of what is now I.C.I. (Explosives Division) at Ardeer, Ayrshire. It has been in successful use there ever since, as well as being adopted by several other sections of Imperial Chemical Industries Ltd. and by a few other firms, research associations and Government departments.[2]

The sphere in which it has proved its worth is essentially that described under (B) on page 238 : to index the existence and the location of every item of information of any kind possessing potential permanent value to the organisation served, which may be contained in any document passing through the hands of any member of the staff—whether in patents, published books, periodicals, or casual articles, in

[1] Many other systems, beyond the scope of this book, are also used. A good short textbook on the subject which includes questions and exercises and numerous references to other works on librarianship is W. C. Berwick Sayers : *An Introduction to Library Classification.* (London : Grafton & Co., 4th edn., 1935.)

[2] Unlike the decimal classification no propaganda is conducted in favour of the Kaiser system, and the handbook describing it in full—J. Kaiser : *Systematic Indexing* (London : Pitman, 1911)—is out of print. A fairly full description by the same author with the same title, followed by a discussion in which several other users took part, is in *Rept. 3rd Conf. ASLIB,* 1926, pp. 20–44. Other references to its use at Ardeer are : W. Rintoul : The control of industrial and scientific information. *Journ. Soc. Chem. Ind.,* 28 Feb. 1918, 67R–68R. W. Barbour : The organisation of a factory library. *Journ. Soc. Chem. Ind.,* 15 Feb. 1919, 37R–40R. W. Rintoul : Library and office organisation for chemists. *Journ. and Proc. Inst. Chemistry,* 1925, Part III, pp. 164–75.

unpublished staff reports on original work and on manufacturing experiences in analyses of costs, output data, labour records, reports made by agents and customers, or in correspondence.

An indication of the nature—not the actual content—of every such item of information is typed on to a 5 inch by 3 inch card together with a call number indicating where the document itself is to be found; the cards are of different colours according to the types of original documents represented, but are all formed into a single interminable series into which new additions are dropped into place daily.

The cards are grouped in the alphabetical order of certain words known as Concretes which are typed for the purpose in their top left-hand corners, and within each group having the same Concrete term they are arranged in the alphabetical order of certain other words known as Process terms typed in the right-hand corners. (Where applicable there may also be a Country term in the middle of the card, which determines the sequence within a batch having the same Concrete and Process terms.) The following are examples of Concrete and Process terms respectively:

AIR	Circulation
COAL	Combustion
COAL	Consumption
COAL	Transporting
FACTORY	Ventilating
GAS	Absorbing
LAND	Draining
PETROLEUM	Analysis
WATER	Filtration

The Concrete terms are either, as above, names of commodities, or else words expressing energy of some kind,

such as LABOUR, POWER, LIGHT, etc.; a rough rule for what is admissible as a Concrete term is "anything that can be bought and sold". The Process terms, on the other hand, denote *dynamic or static conditions of the Concretes*, examples additional to those above being Property, Specification, Ballistics, Nitration, Purification, Occurrence, Yield, Demand, Supply.

Subject to certain rules the Concrete terms can be invented progressively to meet new requirements as the index grows, but the Process terms are selected from a list drawn up beforehand which must not be altered or overlapping and confusion will result. Every five years, however, an entirely new index is begun, and this gives an opportunity for the introduction of any new Process terms which experience may have suggested to be desirable.

It is a fact which may surprise the reader who has not seen such an index in operation, but is confirmed by experience in a wide variety of fields, that the knowledge-content of any item of information can be defined by means of a Concrete and a Process term in this way. The Process term is usually limited to a single word but it is sometimes found convenient to use Concretes of considerable length, the following being actual examples:

BUILT-UP EGG ALBUMIN FILM	Investigation
HEMP-DERIVED PROTO ACID	Property
PARTICLE-SIZE DETERMINATION APPARATUS . .	Description
FILLED CARBON-DIOXIDE CYLINDER . . .	Safeguarding
SHEATHED PERMITTED SAFETY BLASTING EXPLOSIVE	Authorisation
HIGH-FREQUENCY ELECTRICAL-PROCESS-TREATED LOW-TEMPERATURE COAL CARBONISATION PRODUCT DERIVED PETROL	Investigation
TOWN-GAS-FED INTERNAL-COMBUSTION-ENGINE-DRIVEN MOTOR-VEHICLE	Development
INDUSTRIAL ATMOSPHERE CONTAINED TOXIC GAS .	Estimation

It will be noticed as a peculiarity of this system, unlike those described on pages 240 and 265, that the most general idea is stated last, and is *preceded* by the participles or other qualifications necessary to particularise it. Hence cards relating to the same general idea become scattered throughout

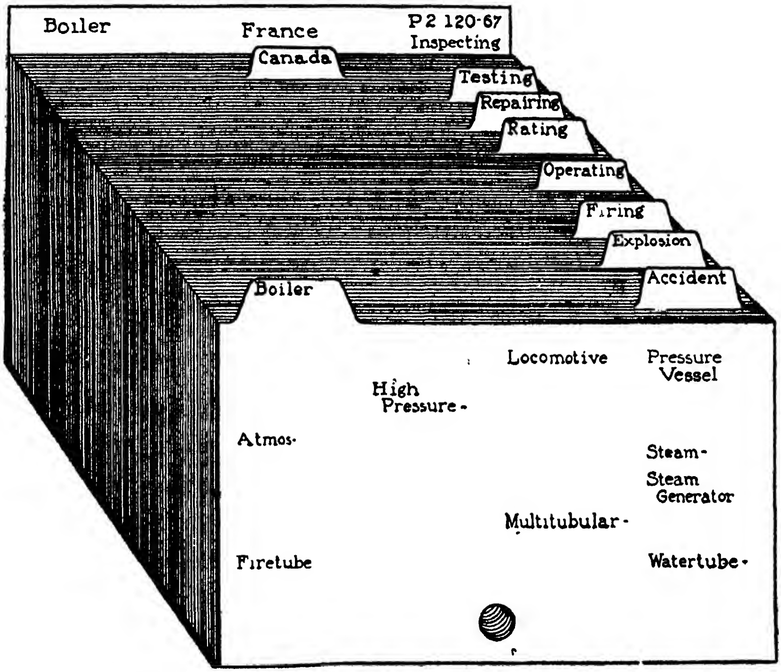


FIG. 6. EXAMPLE OF CARD INDEX ON THE KAISER SYSTEM.

the index according to the letter with which the first of the qualifying words of the Concrete term happens to begin.

This apparent disadvantage is countered by inserting a separate "guide card" in front of the cards for each new Concrete term, as exemplified at the front of Fig. 6. This guide card gives a list of cross references (in alphabetical order) to other Concrete terms under which the idea in

question may already have been indexed. Such cross-references may be synonyms (e.g., Boiler = Steam Generator), "higher collectives" (e.g., Pressure Vessel is a higher collective of Boiler) or "lower specifics" (e.g., Boiler Tube is a lower specific of Boiler). The hyphen stands, in this example, for Boiler.

It is this methodical statement of cross-references on the guide-cards which confers upon the Kaiser system its great merit of flexibility. To quote the words of its inventor—who, it is of interest to note, began his career as a librarian working the Dewey decimal system in America—"I have selected the term Boiler to draw attention to the fact that the meaning of the same term may vary with each business. Thus in a plant driven by electric power supplied locally Boiler would be a specific term perhaps good enough for very casual indexing. In a plant producing its own steam . . . the indexing would have to be much more specific. In a plant producing boilers the term Boiler would literally mean a whole library. This variation of supposed invariables is one of the stumbling-blocks of fixed classification; it requires an elastic system like the alphabetic."

The Kaiser system needs to be worked in strict accordance with its rules, and involves considerable labour using a special typewriter able to reach the extreme top edges of the cards. It is, however, beautifully logical and infallible. Once its principle is grasped classification is less difficult than using the Decimal System, and indexers, provided they are acquainted with the subject matter, are correspondingly easier to train. Moreover, it is much easier and quicker for an inexperienced person to use in making a search, for if he follows the directions on the guide-cards it is impossible for him either to go wrong or to overlook potential sources of the data he is seeking. Members of

laboratory and office staffs do in fact consult it themselves, and in doing so they incidentally pick up many valuable references of which they would remain unaware if the function of searching were delegated to the library staff.

The index is truly analytical : that is to say the indexing staff are responsible for reading the original documents and preparing not one abstract of each document but as many separate cards as are necessary to cover all the points of possible interest therein, and these cards are filed under the respective Concrete and Process terms in different parts of the index. The indications on the cards are just long enough to enable a searcher to judge whether reference to the original document is warranted, in which case he can obtain it by means of the Call Number given on the card.

The cost of this system, as applied by I.C.I. (Explosives Division) to the maintenance of a central index of information from all sources, a " dictionary catalogue " to books and pamphlets, an equipment catalogue and a drawings index, was quoted in the discussion on the ASLIB paper (1926) as £1,380 a year. This figure included everything chargeable to the indexing proper as distinct from other library work and represented about 26 per cent of the total expenditure on library services employing a senior staff of five graduates (one being a translator and one acting as Editor of Reports) in addition to a clerical staff of 12. The more or less regular users of these indexes were stated to include—

58 research department chemists and physicists.
78 members of research department junior staff.
21 manufacturing department chemists.
17 engineering staff.
20 members of head office staff, using the index mainly by proxy.
—
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Rintoul[250·2] describing this index states: "It is reasonable to ask whether or not the results justify the expenditure. The answer is in the affirmative. . . . By the time the index had been running for five years we began to see great possibilities in the advantages to be obtained and, ever since then, these advantages have been increasing and the value of the index has gone up by leaps and bounds" as a means of providing full information for considerations of policy when starting any new research, or for many other purposes.

INFORMATION SERVICES

Technical libraries may be divided into special and general. In the first, at any rate, librarianship means, or ought to mean, a great deal more than looking after books, getting borrowers to sign receipts for them and sending out reminders when they are due back. In Professor Bernal's view,[1] with which I agree, the librarian attached to a laboratory is to be regarded as one of the most important of a team of scientific workers; he should be chosen "partly for his comprehensive scientific interests, which need to be much greater than those of the other laboratory workers, and partly for his inclination to systematic thinking"; his duties should include the watching of current literature to draw his colleagues' attention to items of interest and the drawing up of reports, from time to time, on their current work. A knowledge of languages will further enable him to save much time for those of his colleagues who are not linguists by telling them the gist of a foreign paper without necessarily making a formal translation. In these and similar ways, says another writer,[2] "an information worker of

[1] Page 272 of [76·1].

[2] B. Fullman: Information work as a career for the scientist. *Rept. 12th Conf. ASLIB*, 1935, pp. 38–41.

scientific training who has his wits about him is in a very strong position . . . is bound to acquire a considerable specialised knowledge . . . as time goes on they (his colleagues) come to him not only for information but for advice. He can often offer useful suggestions . . . and exert much influence on the work of his organisation."

A special library or information service working more or less on these lines—though not, of course, necessarily using the Kaiser system—is necessary wherever research is done, and frequently (as at Ardeer, the example described above) the maintenance of an analytical index is associated with the issue of a bulletin of abstracts or references which circulates among members of the staff and serves to keep them *au courant* with the scope and content of the information the library is accumulating for their benefit. The special library staff, in fact, carry out vicarious reading and sifting of the literature on behalf of the research staff proper and supply the latter with material of a kind suitable for them to use either in the way described in the next section or in whatever way personal idiosyncrasy may suggest. (The qualification is important: for whereas some men delight in bibliographical system others, equally productive, abhor it, and attempts to force them in directions theoretically preferable but temperamentally uncongenial may defeat their purpose.)

FURTHER EXAMPLES OF INFORMATION SERVICES

By " vicarious reading " on other people's behalf, I mean keeping oneself constantly acquainted with the changes in their needs for information through personal contacts as close, as frequent and as informal as possible, and in the light of this knowledge of their needs picking out and passing to them any items likely to be of use to them as individuals.

In doing this the aim should be not merely to satisfy their appetites but, what is equally important, to avoid so overfeeding them as to cause indigestion. It is not always easy to decide whether a particular item is really what a busy man is looking for or whether it would merely increase his burden of reading to no purpose, and one's customers are apt to complain, according to their temperaments, either that they are being expected to subsist on odd scraps passed to them without the context or that they are being given unnecessary papers to read. This being the case, I have found it preferable (not actually in scientific information work but under analogous conditions in military intelligence) not to irritate people by sending all of them the same "bulletin" overloaded with irrelevancies, but instead to pass round the original papers to each of those individuals whom they *may* interest, attaching thereto an index card containing a brief abstract of the item in question and also a slip worded somewhat as follows:

> To . . . (Name)
>
> You may be interested to see the attached card which is about to be added to the Index, together with the original text of the item summarised thereon. Please return the card, saying if you wish the abstract amplified or amended in any way.

The recipient can then himself decide from the card whether he wishes to take up his time by reading the original, and has the advantage of seeing it in its context; he also knows he can get it again at any time via the Index. A carbon copy of the slip can be kept so as to make sure the card is returned. This system has the further merit of helping readers to specify their precise needs to the information officer, and of generally educating them in the existence and utility of the Index.

A good example may be found in the information service maintained by the Tin Research Institute under the control of the International Tin Research and Development Council primarily for internal use but also, to a large and increasing extent, for answering outside enquiries.[1] This bureau supplements a regular scrutiny of published abstracts by the preparation of longer ones of its own (often in such detail as to make it unnecessary for the reader to consult the original paper) covering about 150 periodicals. Many of the journals are bound and stored; others are cut up after a week or a month and the separate articles either filed or discarded. British, United States, French and German patent literature is similarly treated, British and American official abridgments being purchased and those which are of interest cut out for filing. Trade literature and photographs are also collected. Wherever possible, reprints of papers are obtained by addressing a request to the authors, and in this way valuable contacts are formed all over the world. All the items filed are numbered (each section in a different series) and card-indexed both by author and subject, using a modification of the Kaiser system. The total number of cards is about 80,000. Stress is laid on the fact that an information service which distributes incoming information to interested quarters can be more effective than one which merely renders information available on request; both methods are used, and the activity of the Council in a consulting capacity as a centre of information relating to tin is steadily increasing.

"The library and information department of a large

[1] *Miscellaneous Publications of the International Tin Research and Development Council*, No. 3, by E. S. Hedges and C. E. Homer: The functions of a technical information bureau (also in *Rept. 12th Conf. ASLIB*), 1935; No. 6, The role of technical information in industrial research and development.

engineering firm" was described by S. W. Gibson in *Proc. Brit. Soc. Internat. Bibliog.*, 1944, 6(2), pages 46–54. "The information bureau of the Electrical Research Association", using the U.D.C., is the subject of a later paper in those *Proc.*, 1945, 7(4). A paper on the corresponding service in the organisation of J. P. Lyons & Co., Ltd., has already been cited at [248·1].

E. H. G. Sargent in his article "Technical information services for smaller firms" (*Indl. Chemist*, February 1946, pp. 99–103) considers that

> if a full-time head of department and secretarial facilities to match are decided on, the cost will be in the region of £1,500 a year exclusive of overhead charges for space occupied, etc. Such a department should be able to survey about 70 monthly and 20 weekly periodicals, prepare about 100 short abstracts a week, carry out translations, prepare summaries of information needed for new projects, co-operate with the firm's patent agents and index all relevant information. Part-time working is, of course, cheaper, but both indexing and abstracting are much more difficult when their preparation is liable to constant interruption.

This cost is additional to that of the journals and their binding. At current prices the latter may cost at least £120 a year for 70 journals, but can be saved, he suggests, by cutting out and filing the articles of interest whilst destroying the rest.

A symposium on the methods used in the preparation and production of information bulletins, house journals and reports appeared in *Rept. 10th Conf. ASLIB*, 1933, covering the Metropolitan-Vickers Electrical Co. Ltd., British Non-Ferrous Metals Research Association,[1] Mond Nickel Co. Ltd., British Cast Iron Research Association and Edgar

[1] For a more detailed description of this particular organisation see A. F. Ridley: Special libraries and information bureaux. *Library Assocn. Record*, Sept. 1925.

Allen & Co. Ltd. Another article[1] on this and related subjects by a librarian operating an index on the Kaiser system may also be mentioned, and Dr. Bradford has stressed the greater services which the central libraries would be able to render to industrial users of literature if all were to adopt the Universal Decimal Classification.[2] For books on the subject see page 223.

INDEX-FILING FOR PERSONAL USE

The system of index-filing now to be described was originally developed by the present author when he was on the staff of one of the engineering institutions and had occasion to organise a bibliographical information service for the members, a function corresponding to (B) on page 238. Since then he has applied it to a number of other organisations and purposes, and as a means of assembling and sorting the material for his own investigations—purpose (C)—extending over a still wider range of subjects. In all these applications it has proved a complete success, and while the principle adopted is so simple that others will almost certainly have hit upon the same thing, a statement of the practical details which the author's experience has led him to standardise may not be without value. This applies particularly to the method of cross-referencing described on page 273, a device which counters, without sacrificing simplicity, many of the objections which exponents of the Decimal Classification are able to urge against alphabetical indexing.

The material indexed for the purpose of the bibliographical information service consisted of published abstracts of the

[1] R. Brightman: Organisation of information for industry—the industrial library and intelligence service. *Indl. Chemist*, Sept. 1936, pp. 396–400.

[2] S. C. Bradford: The organisation of a library service in science and technology. *Engineering*, 23 and 30 Aug. 1935.

relevant literature which were collected from several sources, cut out and pasted on to cards as suggested on page 208 (duplicate copies being purchased in the case of abstracts printed on both sides of the paper), and formed into a cumulative index in such a way that all references to any given subject would be found together regardless of date and origin. Enquiries from members who wished to read up some named topic were dealt with by turning this up in the index—a matter of seconds—and sending them type-written copies of the relevant abstracts or titles by return of post accompanied by an offer to obtain the original articles on loan from a library if desired. It was even possible to answer enquiries over the telephone, holding the receiver in one hand while picking out suitable abstracts with the other and quoting from them with a readiness which must have suggested a surprising degree of accurate erudition on the part of the speaker. Apart from this, many members of the institution formed the habit of periodically dropping in to the office where the carded abstracts were kept and themselves looking through the growing collections on the subjects of interest to them, experiencing no difficulty in doing so as the classification of the cards was clear at a glance from the guides provided. An index-file of abstracts used in this way is especially valuable where few or none of the original periodicals which they summarise are available locally, as it forms a kind of outlying index to what may be borrowed from the large central libraries.

In the index-file for personal reference and research the material accumulated on the cards is of the most miscellaneous kind imaginable. Some of the cards have abstracts or press cuttings pasted or copied on to them; others photostats of statistical tables or folded sheets of typed or printed memoranda attached by means of a stapling press

(but preferably not by slide-on paper fasteners as these are apt to catch on the adjacent cards). Others again contain summaries of conversations, or rough notes of tentative ideas and calculations, typed or scribbled in ink or pencil. Occasional envelopes are interleaved with the cards containing papers too large to attach to the latter ; even printed pamphlets are included, attached to cards if they are smaller or with their margins guillotined off to the same size as the cards if they are larger—the principle followed being, as already stated, wherever possible to incorporate in the index-file the actual data collected rather than a mere indication of where these are located outside it. This is important because the utility of such data depends on their juxtaposition : they are of little use, however well indexed, if buried in separate books and correspondence files which have to be sent for when required ; one needs to be able, by merely turning in one's chair, to pick out at once any relevant item of facts or figures, and, as it were, to play a game of patience by laying them out on the table and trying different arrangements as a stimulus to one's own ideas of how to utilise the knowledge they contain.

The cards should not be too small a size : 8 inches by 5 inches is found convenient, and has the advantage of being the same as quarto sheets of typewriting paper folded in two, so that notes in this form can be kept among the cards. Foolscap sheets, folded unsymmetrically, are also included. Both sides of the cards are used and they should be freely removable from the drawers, not confined by a rod passing through holes near the base (see Fig. 6) as is usual in an index accessible to the public. Another important detail is not to pack the cards too tightly : the user should be able to flick them. It is a good plan to adopt a different colour of card each year so that if the collection is growing unwieldy it is

easy to weed out information which has lost its freshness or value and either to keep this separately or throw it away.

So much for what may be called the mechanical characteristics of the index-file ; we pass now to consideration of how the indexing should be done. In a central index catering for all comers the classification has to be pre-planned, standardised, impersonal : but these very qualities of the Universal Decimal Classification which may recommend its adoption in a central library unfit it for use in a personal collection of data intended, as here, not for the passive storage of references but for the active use of items of knowledge in the integration of new ideas. Properly regarded, the problem of indexing to serve purpose (C) on page 238 differs from that of serving purpose (A) as much as a laboratory differs from a warehouse.

A personal index-file should be so organised as to imitate—though it cannot, indeed, hope to equal—the effortless spontaneity and instantaneous rapidity with which the mind itself is able to evoke from the recesses of the memory any required item of the countless thousands stored away there. (Suppose we set down here some quite unexpected word, the name *Sahara* : then straight away, in the minute fraction of a second which it has taken the reader to pass from that word to the next, the image of whatever he happens to know about the Sahara will have been conjured up before his mind's eye without the slightest conscious effort of any kind.) Even the best memory, however, is limited in scope and accuracy : hence the need for machinery which is able to compensate in these respects for what it inevitably lacks in convenience.

The personal index, then, is to be regarded as an extension of the user's mind which he can keep in a box at the side of his desk, arranging—and if need be freely rearranging—the

material he collects step by step as he goes along, governed solely by, and in this way giving concrete form to, the logic of the picture he is endeavouring to piece together in his inner mind. Any bias impairing his freshness of outlook in doing this is to be deprecated and the arrangement of items of knowledge in accordance with someone else's map of a territory which the searcher has not yet himself explored is the opposite of what is required.

What is needed here is something of the character of the British Constitution by contrast with written constitutions: not pre-plannedness but spontaneity of growth, not symmetry but flexibility, not so much soundness of logic as freedom of adaptation. Moreover the index headings must be mnemonic: the user must not have to waste time and be distracted from his own job—which is *thinking*—in order to look them up in a book.

Such a system is described in the next section.

THE AUTHOR'S SYSTEM OF INDEX-FILING

The majority of subjects, for which there are only a few cards, are filed under single keywords, any confusion due to synonyms being avoided by the system of cross-referencing described in the next section. For the more prolific subjects the principle adopted is similar to that of the Universal Decimal Classification but words are used instead of numbers, and instead of the analysis of each subject being standardised in advance and having to be looked up in a book it is thought out as the index grows. Moreover the successive subdivisions need not be in tens but may be any convenient number suggested by the logic of the subject matter.

The application of this may best be made clear from an actual example relating to the collection and arrangement of material for a partly technical, partly commercial, report on

the subject of Air Conditioning. Data of the miscellaneous kinds indicated above were collected on cards marked, at first, with the single word *Air* in the top left corner. When perhaps 20 or 30 cards had accumulated it began to be troublesome to have to look through the whole batch in order to find a particular one; the existing and all subsequently added cards were, therefore, subdivided by adding a second word suggested by the way the framework of the proposed report was beginning to take shape in the author's mind, as follows:

Air-conditioning	*App*lications
Air	*Dev*elopment
Air	*Eco*nomics
Air	*Ins*tallations (i.e. descriptions of particular plants)
Air	*Mat*erials
Air	*Meas*urements
Air	*Meth*ods

(the non-italicised portion of the word being omitted, on later cards, as soon as it became fixed in the memory). The divisions indicated by the second words were broken down into subdivisions indicated by a third word; these again into subdivisions designated by a fourth word, and so on to as many stages as required—not all at once but step by step to suit convenience as the collection grew—until finally, when the report was ready to be written, it was found that the cards had sorted themselves out into the following scheme:

Air-conditioning				
	*App*lications			
		*Agri*cultural		
		*Clin*ical		
		*Com*fort		
			*Rail*ways	
				*Aus*tralia
				L.M.S.
				U.S.A.

			Ships		
				A (Names of ships)	*Naval*
		*Ind*ustrial	(Names of industries)		
	*Dev*elopment				
		A (Names of countries)	*Tropics*		
	*Eco*nomics				
	*Ins*tallations	(Locations thereof)			
	*Mat*erials				
		Cu = copper			
		*Insul*ation			
		(Etc.)			
	*Meas*urements				
	*Meth*ods				
		*Cont*rols			
		*Dehum*idification	*Abs*orption		
			*Ads*orption		
			*Cond*ensation		
		*Fil*tration			
		*Refr*igeration			
			Steam-jet		
		*Ster*ilisation			

The following is another actual example of how material was collected for writing a report on the subject of Roads from several rather special points of view :

Roads				
	*Acc*idents			
	*Anc*illaries			
		A	*Metals*	
		Cycle-tracks		
		Fences		
		*Ligh*ting		
			A	*Deptl. Ctee.*

		Electric		
			*Vap*our	
	Signals			
	Signs			
	Studs			
	Tree-planting			
Cleaning				
*Fin*ance				
	A	A		
		Motorways		
		Trunk		
	(Names of countries)			
*Mat*erials				
	A	A	A	(Names of countries)
		*B. S. Spec*ifs.		
		Census of Prodn.		
		Surfaces		
			Coloured	
	*Asph*alt			
	*Bit*umen			
		*Emul*sions		
		Rubber mixture		
	Brick			
	$CaCl_2$			
		Dust-laying		
		Ice-Prevntn.		
		*Stab*ilisation		
			(Names of countries)	
	Cement-bound			
	Concrete			
		Breaking-up		
		Costs		
	Cotton			
	NaCl			
	NaSi			
	Paint			
	Rubber			
	Slag			
	Stone			

		Tar
		Tarmac
		Tar-Rubber
		Wood
Traffic		
Vehicles	A	*Taxation*
	Gas-operated	
	Horsed	
	Motorcycles	

In the aforementioned index-file of engineering abstracts the most prolific subject was that of Bridges, classified as in the following examples—

Bridge	*Concrete*	*Arch*	*Design*
Bridge	*Steel*	*Arch*	
Bridge	*Steel*	*Plate-Girder*	*Design*
Bridge	*Steel*	*Truss*	*Erection*
Bridge	*Timber*	*Beam*	

the second word always denoting the material and the third the type of bridge while the fourth (where necessary) was what Kaiser would call a Process term and a fifth might also be added stating the location of the bridge. On the principle explained below, a card dealing with the general subject of arched bridge design not referring to any particular material would be indexed as—

Bridges	*All*	*Arch*	*Design*

and one dealing with bridge foundations in general as—

Bridges	*All*	*All*	*Foundations*

(the plurals being ignored as regards the filing sequence).

The material for the present book has been collected on the same principle, the initial word being *Know*ledge (because the originally contemplated title of the book was *Technical*

Knowledge) and the second word (further divided and subdivided as necessary) *Abs*tracts, *Bibl*iography, *Bur*eaux, *Edu*cation, *Ind*exing, *Lab*oratories, *Lib*raries, *Micro*photography, *Org*anisations, *Pa*tents, *Psych*ology, *Rep*roduction, *Res*earch-Objectives, *Soc*iological, *Stand*ardisation, *Stat*istics, *Tests*, *Theory*, *Univ*ersities, *Works*-Management, *Writ*ing—a sequence which sufficiently illustrates how logic has been subordinated to convenience. If this were all, the system would rapidly become unworkable, but it is in fact redeemed from any tendency to breakdown or confusion by the two simple devices which remain to be described: the use of the letter *A* by itself which the reader will have noticed in the examples given above and the method of cross-referencing as explained in the next section.

The letter *A* (or if preferred the word *All*) serves the same purpose as does the zero among numerals; that is to say it has no significance in itself but determines the position value of the digit coming after it. For instance, the word that follows *Roads—Finance* above is the name of the country in question; suppose, however, it were required to insert a card on the subject of the financing of motorways which did not refer specifically to any one country; if this were indexed as *Roads—Finance—Motorways* it would have to be filed between *Roads—Finance—Morocco* and *Roads—Finance—Norway*, the objection to which is obvious. To avoid this, such a card would be indexed as *Roads—Finance—A—Motorways*, the *A* bringing it to the front of all the cards subdivided under countries in the third word, and thus indicating a new possibility of subdivision in the fourth word (e.g. it would allow the insertion of cards on *Roads—Finance—A—Trunk*).

By an extension of the same principle the letter *A* may, if necessary, be used several times over, as for instance to

introduce a card marked *Roads—Materials—A—A—A—Scot*land.

Fig. 7 shows the appearance of a collection of cards on yet another subject. Wherever there are more than two or three cards in a given subdivision these are preceded by a guide-card with a projecting flag, in the appropriate position, bearing the full name of that subdivision with the abbreviated portion of the name underlined; the " flags " are cut from gummed linen strip which can be bought in 6-inch lengths, price 2*d*. each; they are made 1 inch long and spaced out in 1-inch steps. If the next heading has not yet been decided or if there are not enough following cards in the subdivision to make it worth while to show their designation on such a flag, a blank flag should be inserted in the appropriate position to mark the *end* of the batch of cards on the subject to which the previous flag relates. It makes for clarity if the indexing words which are written below the top edges of the cards are likewise spaced out at 1-inch intervals so as to come immediately behind the respective guide-flags, and it might be worth while having a rubber stamp to divide the top of the cards into 1-inch spaces to facilitate this; as shown in Fig. 8.

In order to take full advantage of the flexibility which is the chief merit of the system here described it is desirable occasionally to re-classify some of the cards when progress in the collection of information on a given subject suggests a more convenient arrangement than that adopted at first. This in itself stimulates constructive thought, and it is made easier if the indexing is done in pencil which can easily be erased and altered.

If many references are collected which already bear U.D.C. reference numbers printed on them it may be preferred to turn the latter to account by keeping them in

numerical sequence in a separate cabinet, in which case the alphabetical key to those parts of the U.D.C. under which

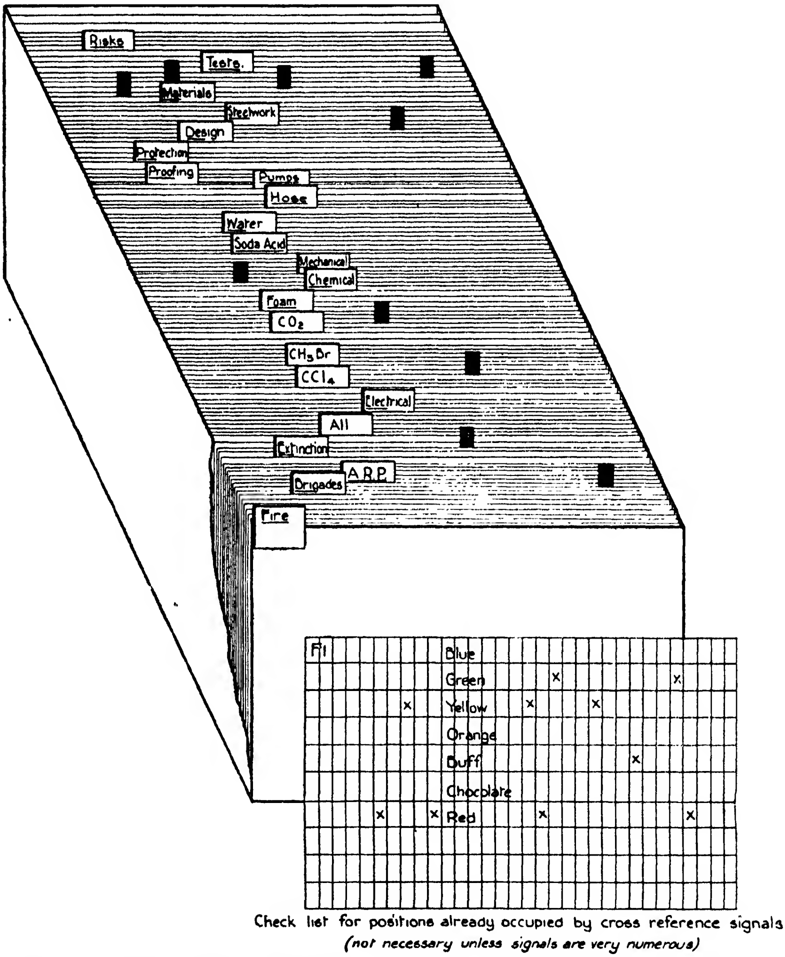

FIG. 7. DATA FOR A REPORT ASSEMBLED IN AN INDEX-FILE BY THE AUTHOR'S METHOD.

references have been collected can be interleaved with the cards indexed alphabetically as suggested here. In this way one would, so to speak, get the best of both worlds.

CROSS-REFERENCING BY COLOURED SIGNALS

Cross-referencing means a device for directing a searcher to information which relates to his quest but is contained in another part of the index than where he is looking. This is necessary because many items admit of equally logical classification under more than one heading or are of possible interest from more than one point of view and, therefore, are liable to be missed through the searcher not happening to turn up the particular headings under which the indexer happens to have buried them. Whatever system of indexing is used cross-referencing is the crux of the problem.

One way of meeting it is that adopted by users of the Universal Decimal Classification who, as explained on page 247, simply repeat any card which relates to more than one subject under each of its several relevant headings; but where anything longer than a title is involved this necessitates an excessive amount of copying work and for the index-filing of abstracts or notes as here contemplated it becomes quite impracticable. Using the Kaiser system (see page 253) the cross-references are shown on the guide-cards: but, like those irritating words "see——" and "see also——" in other indexes, they serve only to direct the searcher to a *batch* of cards *among which* he may find one or more cards giving what he needs; they cannot be used as a means of directing him straight to one specific card in the collection as a whole.

The device now to be described does this, and does it so quickly that the number of seconds taken to find a card from its cross-reference is less, if anything, than that needed to pick out a particular card from its already known subject heading. Moreover the preparation and insertion in the index of "arrow-head cards" for originating cross-refer-

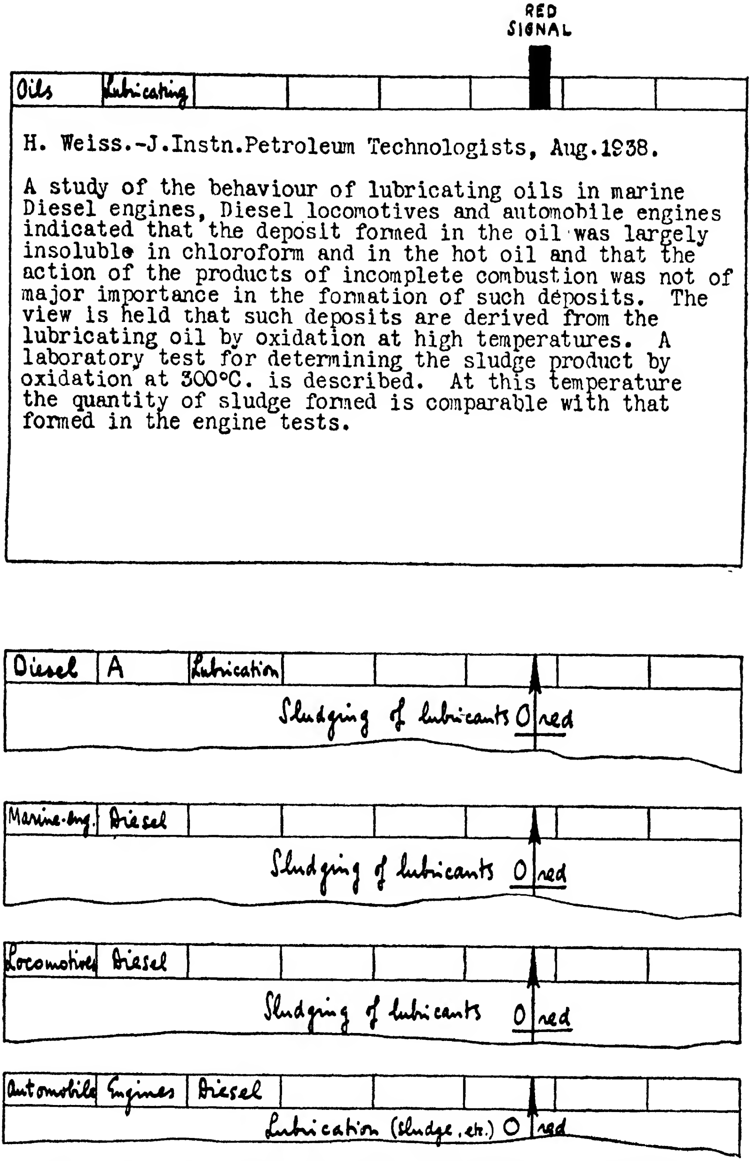

FIG. 8. THE AUTHOR'S SYSTEM OF CROSS-REFERENCING BY COLOURED SIGNALS.

ences, as explained below, is so easy and rapid (involving no copying at all) that no temptation arises to be parsimonious in providing these wherever there is even the slightest chance of their being useful—and as long as this has been done it does not much matter whether or not the card bearing the actual information has in fact been classified and filed in its most logical position.

The method adopted will be clear from the example in Fig. 8, representing an abstract which by virtue of its general subject has been indexed under *Oils—Lubricating* but which might evidently be of interest also to someone looking for information under the headings *Diesel*, *Marine-Engines—Diesel*, *Locomotives—Diesel*, *Automobile Engines*, *Lubrication*, *Sludge* or perhaps others, including synonyms of the aforementioned such as *Motor Car—Engines*. What is done in such a case is to attach a coloured signal—let us say red—to the top edge of the card in any previously unused position, and to insert a card under each of the other headings bearing an arrow marked " O *red* " which means " look in the drawer containing the O. . . cards for a red signal in this position, and you will find something of interest ".

The indication written on the arrow-head card should be sufficiently detailed to guide the searcher straight to the right drawer of the cabinet ; if, for instance, the index is of such a size that the cards beginning with O fill more than one drawer it will be better to put " Oi *red* " or even " Oils *red* "—but even so the labour involved cannot be deemed excessive. As a rule the distance of the arrow-head from the end of the card can be estimated by eye and the required signal identified in the act of pulling open the drawer, but if the signals are unusually crowded the arrow-head card can be taken out and held over the drawer in question to serve as a gauge. The signals, ¼ inch wide, are

cut from the same kind of gummed linen strip as is used for the 1-inch flags on the guide-cards, this being obtainable in many different colours and being cheaper as well as, in the author's experience, more satisfactory than metal signals.

As there is room on an 8-inch card for 32 different positions of such signals, it is possible, using 10 colours, to obtain 320 different combinations in each drawer, or enough for about every third card to be signalled if necessary. Even if this should be insufficient there is nothing to prevent the use of combinations of colours, or of numbers written on the signals. A special card may be kept at the front of each drawer on which to tick off, as illustrated in Fig. 7, which colours have already been utilised in which positions so far as that drawer is concerned.

It may also be convenient to extend some of the signal indications throughout the whole of the index instead of limiting them to particular groups of cards : for instance, in an index file of abstracts on engineering structures a blue signal in a particular position was used to indicate the presence of information on welding (if attached to a card relating to a reinforced concrete bridge it marked the fact that the reinforcement therein had been welded) and similarly a yellow signal in a given position served to mark those cards which included references to the economic or costing aspects of the structures in question. In such a case the arrow-heads are marked A–Z.

In the same way arrow-head cards may, if so desired, be provided under authors' names, guiding the searcher to signals attached to whichever cards contain references by particular authors.

This method of cross-referencing was developed in connection with the author's system of alphabetical indexing but it is equally applicable to any other system, including

the Universal Decimal Classification, the only difference being in the marking of the arrow-heads which might take such a form as "*621* blue", quoting, as before, sufficient digits to identify the particular drawer in which the cross-referenced card was to be found.

REVERSED ALPHABETICAL FILING OF CARDS

Fig. 9 shows the same cards as Fig. 7 (page 272) arranged in reversed order, the alphabetical sequence running from back to front of the drawer instead of from front to back; an arrangement which has certain advantages and has been developed by the author since the first edition of this book.

The system of heading each card with a succession of class terms written in one-inch spaces at the top, each such term a functional, geographical or other logical subdivision of the term on its left, is the same as before but is carried a step further. That is to say, each individual card—not merely each batch of cards—is distinguished from the next by having its "rightmost" class term different from the "rightmost" terms on its neighbours. For instance, the FIRE—BRIGADES—A.R.P. cards, which in Fig. 7 were classified no further than that, bear in Fig. 9 a fourth term distinguishing them by the name of the place, such as (in this fictitious example)—

FIRE—BRIGADES—A.R.P.—WOLVERHAMPTON

One advantage of this is that it provides a quick and infallible method of cross-referencing which may be preferred to the use of coloured signals as explained above. For instance, were it desired to refer across from another part of the index to some item of information embodied in the card chosen as an example in the preceding paragraph,

this would be done merely by quoting abbreviations of the class terms which identify that particular card, namely

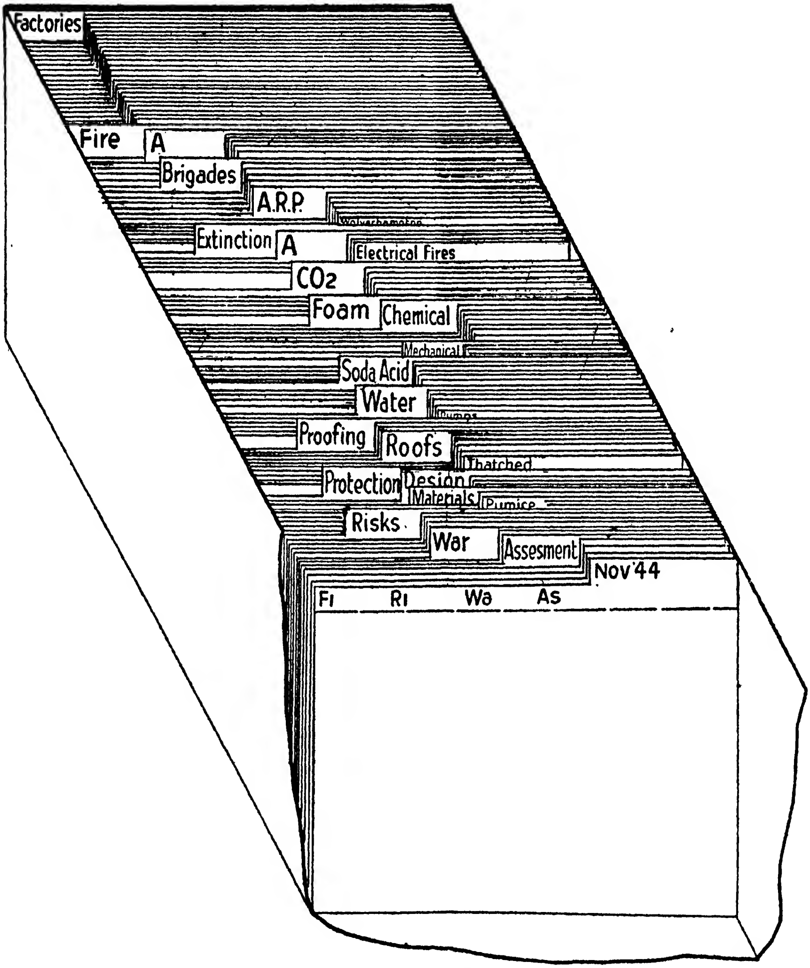

FIG. 9.—REVERSED ALPHABETICAL FILING OF CARDS.

" Fi—Brig—A.R.P.—Wolv". Abbreviations can freely be adopted for this purpose since, if there should be any doubt

as to their meaning, it is resolved at once by looking at the index itself.

Guide flags are not used; which saves time, stationery and bulk. Instead, the rightmost term on each card is written in full in the appropriate one-inch space just below the top edge, whereas all the terms in the spaces to its left are abbreviated and are written half an inch lower down (just above the red line which is printed on the card), with a notch cut away above them by two snips of the scissors so as to expose the collective class term on the card behind which begins the batch so classified.

By this means all except the "rightmost" terms on most of the cards can be read without having to finger the cards, and it becomes very quick and easy to pick out a particular one. This notching of the cards, combined with their back-to-front sequence, might be applied with equal advantage to cards classified on the U.D.C. system.

THE INTEGRATING OF IDEAS TO FORM NEW KNOWLEDGE

Using the system of indexing last described the cards arrange themselves in a way which reflects the personality and point of view of the indexer; different men would arrange the same cards differently. For purpose (A) on page 237 this fact would be intolerable and would justify all the strictures of the decimal enthusiasts; in an index of type (B) it would be debatable; in an index of type (C) it is as it should be—for here the purpose is not merely the passive collection of items of knowledge but their marshalling in a state of increasing readiness for active deployment in accordance with the plan of campaign taking shape in the researcher's mind.

Day by day, cards have been added containing not only

second-hand knowledge but also ideas of one's own interleaved with the others in proper logical sequence; the process has been continued until every gap is filled—and behold, of a sudden, the completely articulated skeleton of the report or paper one is trying to write, waiting only to be clad in literary flesh and muscle before starting out on its career as a new and living entity in the world of knowledge.

In my experience it is nearly always worth while, though laborious, first to abstract the original information on to cards in this way, interpolating one's own ideas on other cards as they suggest themselves, rather than attempt to copy it direct into the draft of the report or paper one is writing. It is, in fact, the use of some such mechanism as this which differentiates critical collative research from mere "scissors and paste".

Not that "scissors and paste", even by itself, is an activity to be despised. Provided its character is frankly proclaimed so as not to masquerade as original work it often serves a very useful purpose.

CLASSIFICATIONS OF PATENTS

The advocates of the Universal Decimal Classification have not yet succeeded in converting to its use the Patent Office of any nation except that of the Netherlands, which prints U.D.C. numbers along with its own classification marks.

For the purpose of classifying patent specifications and the published abridgments thereof each country uses its own system. That adopted by the British Patent Office (described by E. M. Bennett in *Proc. Br. Soc. Intl. Bibliog.*, (7), 1–9, 21 February 1945) has developed progressively since 1860. It is a grouping of about 2,000 subject headings into 271

classes and these in turn into 40 main groups. The headings are qualified wherever necessary by "including" or "excluding" ("other than——") notes, or their scope is defined in a longer "italic" note, and by these means the headings themselves are kept brief. In 1927 an alphabetical index to the classification was printed as a separate volume. When necessary, as the technical art changes, parts of the classification are rearranged to suit the work of the examiners; for instance, "fluorescent screens", originally classified under "X-rays", now appear under "luminescent materials". Under the Patents Act, 1902, the Comptroller is required to make a search of novelty in respect of every patent application; the system is designed to facilitate this, and it would not be suitable for literature—such, at least, was the opinion of one speaker in the discussion on the above-mentioned paper, who had tried it.

The American system is published in the U.S. Patent Office *Manual of Classification and Patents*, 1940, which contains 336 pages of classification and 73 pages of alphabetical index thereto.

AUTOMATIC SORTING

It is evident, in theory at least, that the principle of the punched card systems which are used in accounting, statistical analysis and census work might find applications also in indexing and collative research, particularly if it were combined with microphotography. Probably the most imaginative article that has appeared on this and related ideas is one entitled "As we may think" in *The Atlantic Monthly*, July 1945, by Dr. Vannevar Bush, an authority whose scientific work in the war (see page 193) forbids us to discount him as a mere visionary. Dr. Bush describes in imagination a machine he calls a "Memex" whereby the

scientist, on keying a code number, could instantaneously conjure into view on a screen before him any desired page of any book or of the index thereto, and record his thoughts thereon by a speech-actuated typewriter ! Moreover—

> All this is conventional, except for the projection forward of present-day mechanisms and gadgetry. It affords an immediate step, however, to associative indexing, the basic idea of which is a provision whereby any item may be caused at will to select immediately and automatically another. This is the essential feature of the memex. The process of tying two items together is the important thing.
>
> When the user is building a trail, he names it, inserts the name in his code book, and taps it out on his keyboard. Before him are the two items to be joined, projected on to adjacent viewing positions. . . . The user taps a single key, and the items are permanently joined. . . . Thereafter, at any time, when one of these items is in view, the other can be instantly recalled merely by tapping a button below the corresponding code space. . . .

Descending to earth, we may note, first of all, that before the war an addressing machine (the Adrema) was in use at the Technische Hochschule, Berlin, for printing the cards of abstracts mentioned here on page 213. The plates, stored like a card index, could be placed in the machine to print at the rate of 5,000 cards an hour, or alternatively to print in a continuous list from successive plates.[1] Moreover, the machine could be set to print references on selected subjects automatically, the plates having embossed projections in one or more of 13 possible positions to engage with selector switches or stops on the machine : if, for instance, the librarian was asked what literature he had on transport published in periodicals, with particular reference to America but written in the German language, he set the machine to

[1] A. Predeek : An ever-printed catalogue. *Rept. 8th Conf. ASLIB*, 1931, pp. 41–9. Also described by Spratt in his book quoted on page 223.

correspond with these particulars and turned the switch, whereupon the machine proceeded to search through the index plates at the rate of 70 a minute and print those which were applicable.

A very small step nearer to Bush's imaginary " Memex " can be secured without any elaborate apparatus at all by adapting to bibliographical indexing the Paramount or Copeland-Chatterson system of cards (which is described in the book by Connor quoted here on page 28). These cards have a row of holes punched close to all of their four edges, and the holes are marked in accordance with a coding system: they could, for instance, be made to represent U.D.C. numbers (see page 244) or any other classification of concepts. Whatever is recorded on a particular card is coded by converting the appropriate holes to slots opening on to the edge of the card, by means of a hand punch. Whenever it is desired to sort out from the others all those cards which have been coded in a particular way, it is merely necessary to pass a knitting-needle through each hole in turn which corresponds to that coding and to lift it, whereupon the cards which have *not* been so coded remain suspended on the needle whilst those which have had the hole converted to a slot drop off. An application of this is described, and six other references are cited, by G. J. Cox and others in " Punch cards for a chemical bibliography ", *Chem. and Eng. News* (New York), 25 September 1945, pp. 1623–6.

Wider possibilities suggest themselves in the Hollerith and Powers-Samas electro-mechanical card sorting and integrating apparatus. These, however, are elaborate and expensive. They do not appear to have been applied to bibliographical work on any large scale, but there is a short chapter on this among the references to medical, legal, agricultural, statistical and other research applications in a

book edited by G. W. Baehne : *Practical Applications of the Punched Card Method in Colleges and Universities* (New York : Columbia Univ. Press, 1935).

The advantage of punched cards over visual sorting is that they save the need for multiple entries or cross-references, as any possible *combination* of the coded concepts can be picked out in a single operation. Moreover, the cards need not be filed in a regular sequence but can be kept mixed at random. On the other hand, if this is done the whole store of cards must be passed through the machine on every occasion of search, and if they number many hundreds of thousands this may take hours.

Nor should we forget that the mere extraction of those cards on which idea A is juxtaposed in the same document with idea B is only the first step towards ascertaining what significance or value, if any, attaches to the juxtaposition. It may be merely fortuitous ; and the evaluation and development of those ideas can be done only by a human mind versed in the subject matter under examination. The point may seem obvious, but there is danger here of falling into the fallacy of the over-confident young journalist who undertook to produce at short notice an article on Chinese philosophy by looking up " China " and " philosophy " in the encyclopædia and " combining his material ".

CHAPTER EIGHT

THE EXPRESSION AND TRANSMISSION OF FACTS AND IDEAS

INTRODUCTION

LOOKING upon documents as vehicles of knowledge, we have now discussed the best ways to unload them and sort out their contents, and it remains to consider how newly integrated knowledge, in its turn, is to be loaded and dispatched on its journey.

The media available for transmitting technical knowledge from one mind to another are various, but none are perfect in the sense of being certain to produce in the mind of the recipient an undistorted image of the ideas sought to be conveyed by the originator. Nor are all media applicable to every kind of knowledge, and where there is a choice their order of faithfulness is partly a matter of opinion. They will be discussed here in my own estimation of that order: graphics, mathematics, the spoken word and the written word.

GRAPHICS

The kinds of relationships which admit of graphical expression may be spatial, ideal or numerical.

The first of these headings covers maps, engineering drawings [1] and photographic views; three kinds of docu-

[1] There is everything to be said for standardising the details of graphical work in accordance with British Standard Specifications Nos. 308, *Engineering Drawing Office Practice*; 108, *Graphical Symbols for General Electrical Purposes*; 530, *Graphical Symbols for Telephony, Telegraphy and Radio Communication.*

ment which are invaluable in technical work. Thus a contour map tells the civil engineer, the geologist or the soldier more about the configuration of the ground than any number of words, and with such precision that he is enabled to ascertain distances, levels, bearings and vertical angles with the certainty of coming even closer to the truth than if he took his own measurements on the ground itself. Similarly, a Chinese foreman supervising the assembly of steel bridge parts shipped from England can ensure that every detail is as the designer intended, simply by following the drawings prepared in an office thousands of miles away by someone whose language he cannot understand.

From diagrams of dimensions it is a natural step to diagrams of non-spatial relationships such as electrical connections, " flow sheets " showing the sequence of operations in some process of manufacture, or charts showing the devolution of authority in an organisation. Graphics can sometimes be used to convey even abstract ideas more faithfully than any verbal explanation, or to assist the latter by keeping those parts of a complicated situation which have already been explained continuously before the mind's eye while other parts are being explained. It would have been difficult, for instance, to convey the sense of the opening chapters of this book without making use of the endpaper chart.

Through Descartes' great invention, co-ordinate geometry, graphics can be applied also to express relations between numerical variables and nowadays everyone is familiar with diagrams in which temperatures, barometer readings, index numbers of business activity, etc., are " plotted ". The advantage mentioned in the preceding paragraph applies here also, with the further one that a graph can be drawn in such a way as to avoid the spurious

suggestion of literal accuracy which is apt to be given by presenting the same data in the form of a table of figures. If experimental data are plotted as points in a graph the reader can form his own estimate of the justification that exists for drawing a smooth curve between them.

Higher developments in the technique of representing mathematical relationships graphically enable more than two variables to be inter-related in a single chart, and by this means it is possible to make a few simple readings give the same result as would otherwise necessitate a long and difficult calculation. These alignment charts or nomograms, as they are called, are much used in certain branches of engineering such as hydraulics and air conditioning [26·1].

The following books may be found useful :

K. G. Karsten : *Charts and Graphs.* (New York and London : Pitman, 1925.) This is described in its sub-title as " an introduction to graphic methods in the control and analysis of statistics ", but its scope is wider than these words suggest, including also " non-mathematical charts " such as maps and diagrams, etc., calculating charts, and appendices on the practical side of draughtsmanship. 734 pages.

H. Arkin and R. R. Colton : *Graphs—How to Make and Use Them* (New York and London : Harper, 1936) is another general work (but shorter) dealing with line graphs, ratio charts, area and solid diagrams, scatter diagrams, organisation charts, graphs for computations, etc., with a useful chapter on methods of reproduction.

W. J. Kerton and G. Wood : *Alignment Charts for Engineers and Students.* (London : Griffin, 1924.)

H. J. Allcock and J. R. Jones : *The Nomogram—the Theory and Construction of Computation Charts.* (London : Pitman, 1932.)

MATHEMATICS

The utility of mathematics is not limited to the making of practical calculations. Without mathematics, it has been said, scientists could no more describe their discoveries

accurately than a bird can express how it feels without singing. Mathematics, like music, is a language in which it is possible to say things which cannot properly be translated into word-languages at all, and among these things are some that are vital to the understanding and control of our material environment; hence the fundamental importance of mathematics in the training of engineers and other practitioners in any of the exact sciences. "I have found by experience"—wrote a gifted interpreter of science to the layman—"that men of but literary education, highly intelligent, logical, imaginative, have all their mental powers instantly paralysed by the sight of a mathematical symbol"; whereas to the initiated reasoning in terms of mathematics seems like swimming in clear water and reasoning in words like floundering through a bog.

As explained in Chapter Two, each department of science seeks to express its laws as mathematical formulæ and to evaluate experimentally the constants therein. The application of these formulæ to practical problems in engineering design, surveying, statistical analysis, the compilation of tables, etc., is known as computing and, when lengthy or repetitive, calls for a type of mind having no necessary affinity with that of the original researcher. Nowadays the arithmetic is largely done on machines worked by operators who themselves need possess no knowledge of science or higher mathematics but are controlled by mathematicians skilled in the organisation of arithmetical teamwork so as to combine speed and efficiency with rigorous cross-checking. An interesting development in this connection is the bureau in London known as Scientific Computing Service, Ltd., which (besides conducting instructional courses) undertakes such work under contract, including, for instance, harmonic analysis, the evaluation of integrals,

etc. It is equipped for the purpose with every variety of calculating machine and is staffed by mathematicians of high attainments.

This is not a matter which can usefully be pursued further here but two books may be recommended to the casual reader who, without needing or intending to acquire the technique of mathematics himself, desires to learn what mathematics is: A. N. Whitehead: *An Introduction to Mathematics* (Home University Library, 1924) and, a larger but popular work, Lancelot Hogben: *Mathematics for the Million.* (London: Allen & Unwin, 1938.)

In the application of mathematics to practical ends the important thing is to plan the work in a methodical way which will ensure that each step in calculation is done twice over by different methods and preferably by different people, so as to reduce the risk of silly mistakes like misplacing a decimal point or forgetting to multiply something by two. For instance, I have known a railway engineer overlook the fact that a railway has two rails. It is the easy things like this, far more than the difficult things on which one's mind is concentrated, that are apt to make one look foolish; and the only safeguard against them is checking, checking, checking.

If words were used with completely different meanings as between one book and another, compelling each author to supply a glossary of the words he proposed to use, it would be deemed an intolerable state of affairs; yet, until recently, this is exactly what has been allowed to happen in regard to the symbols used for the mathematical expression of physics and engineering. Such symbols, as well as abbreviations for the names of units of measurement and physical concepts, have now been standardised by agreement between the interests concerned and are listed in British

Standard Specification No. 423 (1931) relating to all branches of engineering, where the hope is expressed that all authors, teachers and students will make a point of using them.

SPEAKING

Words are vaguer, but wider in scope, than either graphical or mathematical expression, and their skilful use is a matter of great importance in technology.

Ideas can be driven home more certainly in conversation than by writing because a speaker's personality, unconsciously affecting his intonation and gesture, subtly reinforces the impact of his words on a hearer ; also because any lack of understanding is immediately apparent and can be corrected straight away, and because the greater speed enables reiteration.[1] Yet technical men too often fail to appreciate that it is worth while giving some attention and applying some self-discipline to the way they converse or, still more, address an audience. Inaudibility or over-loudness ; a delivery too fast, too slow or too staccato ; irritating mannerisms or distracting fidgets, often prevent a speaker from doing himself justice. It is worth while at least to ask a candid and observant friend to point these things out, and those (such as officers of societies) who have frequent occasion to speak or read aloud in public should take lessons.

Inventions for the transmission and recording of speech are lending the spoken word a new importance. Conference proceedings, nowadays, are facilitated by the installation of microphones and loudspeakers, and the circuit may include apparatus for obtaining a continuous record of what

[1] On the other hand, as the Army training instructors put it, " the brain retains more readily and firmly what it sees with the eye than what it hears with the ear ". Hence the importance of taking notes of spoken ideas : see pages 32 and 227.

is spoken, such as the Telediphone which uses wax cylinders or the Textophone mentioned on page 296.

It is not commonly known that the General Post Office provides for the holding of telephonic conferences over the trunk lines between subscribers in different towns, all of whom are thus enabled to hear each other speak as if they were in the same room. The charge made is the sum of the normal trunk-call charges for personal calls from the originating station to each of the called numbers, plus a fixed additional sum of ten shillings irrespective of the number of stations connected and an extra charge if loud-speakers are supplied enabling any number of people to participate at each station. Even for a fairly long "meeting" this would normally work out less than the cost of all the participants travelling to a central point, apart from the saving in time. On the other hand rather special secretarial arrangements are necessary in view of the impossibility of passing round documents and the chairman must use a special technique as he cannot see which members wish to speak. Perhaps these handicaps will be overcome when telephony is accompanied by television.

WRITING

What some technicians write is as emetic as the worst commercial jargon; but there are others in whose hands the language acquires a special beauty from the concreteness and impersonality of the subject matter and the sober pleasantness of the images evoked. It would be futile to attempt to teach here in a few pages the art of good writing but a few points of advice may be set down.

Observe, in the first place, that writing is simply a fixation of thinking: good writing follows from, and also stimulates, clear thinking; the two things are reciprocal

and conscious effort to achieve the one automatically affords training in the other. And just as clear thinking means thinking in which the things thought about and the relations perceived between them stand sharply out against their background, unfogged by irrelevancies, so good writing means terse and accurate writing: the economical use of words unclogged by verbiage; words hand-picked for the certainty, aptness and nakedness of their meaning, and used as tools of precision. Above all, then, *be terse*: strike out from your draft every word which can be removed without making a difference to what remains. In this respect there is no better exercise than that of making technical abstracts wherein exigencies of space force the composition of such a sentence as the following—

> The Kanda[1] river[2], 90 ft.[3] wide, was underpassed[4] after[5] cofferdams[6] had been[7] formed to divert[8] the flow through a steel[9] flume 20 ft.[10] wide, 60 ft.[11] long, and 11 ft.[12] high, to provide for barge[13] traffic, which was lowered[14] to rest on two[15] lines of sheet-piling[16] previously[17] driven[18] to bed level[19] across[20] the river [1]

a sentence in which 20 separate statements or ideas are compressed into a total of 55 words without rendering it unpleasant to read.

As a corollary to the need for terseness, *be precise*, especially in the use of technical terms, and pay due respect to accepted technical conventions. Electrical engineers, for instance, have made praiseworthy efforts in this direction,[2] seeking, in British Standard Specification No. 205 (*Glossary of Terms*

[1] The Tokyo Underground Railway, Japan, No. 239 in *Eng. Abs.*, *67*, April 1936.

[2] E. W. Ashcroft: Technical English—some considerations on the vocabulary of modern sciences with special reference to that of electrical engineering. *Rept. 6th Conf. ASLIB*, 1929, pp. 85–90.

and Definitions used in Electrical Engineering), to standardise and co-ordinate the electrotechnical terms used by British engineers and to provide a basis for the British portion of an international vocabulary in preparation by the International Electrotechnical Commission. As an example, the use of the termination *-ance* (resistance, conductance, etc.) is differentiated from that of *-ivity* (resistivity, conductivity) in accordance with certain agreed rules.[1]

The most rigorous precision of language is that required in the drafting of patent specifications (enlivened, though these are, by what the writers in question would call "a plurality" of curious turns of speech).

Thirdly, *be purposeful*: do not write *around* a subject but assemble the logically necessary data and then proceed from them to some definite conclusion. Having made up your mind what it is you want to assert, assert it boldly and downrightly for all the world to take note that you stake your reputation thereon: if, then, the world accepts your statement, good; if on the other hand your statement is unsound the more openly it is left exposed to challenge and attack the less the harm you have done. Avoid faint-hearted expressions of opinion like the following extract from the report of a Government committee[2] some years ago:

> With regard[a] to addressing-machine stencils, these[b] constitute a heavy load of a dangerous type, and there seem[1] to be grounds[2] for

[1] Other British Standard Specifications dealing expressly with terminology are Nos. 46, Keys, Keyways, Splines and Serrations; 63, Road Stones; 185, Aeronautics; 204, Automatic Telephones; 233, Illumination and Photometry; 491, Timber for Aircraft Purposes; 499, Welding and Cutting; 531, Birch Plywood; 565, Hardwoods and Softwoods; 588, Grading for Plywood; 589, Softwoods; 661, Acoustics; 719, Railway Signalling.

[2] No—it shall be nameless.

> [3] suggesting that the manufacturers be [4] approached with a [5] view to [6] discussing the [7] possibility of [8] some warning being given in the catalogues or marked upon the boxes,

the writer of which had to take two separate runs at it (marked *a* and *b*) before he could pluck up courage to engage his idea at close quarters and even then was so overcome with his own boldness that he felt it necessary to insert no less than eight pieces of padding (here numbered 1–8) to deaden the shock of his idea that these stencils are dangerously heavy and the manufacturers ought to say so.

Good prose should have a crisp, crackling sound. Avoid whatever tends to deaden this, such as needless adverbs and adverbial phrases like those in the sentence which I was able to strangle at its birth in the draft of a paper I had to edit: " in due course, their use for that purpose may quite conceivably be even more considerable ". (What does " in due course " mean? Why " quite " conceivably?) Note, likewise, how often the word " very " —a word which should *very* seldom be used—detracts from rather than adds to the native vigour of the adjective in such phrases as " a deep well ", " a high mountain ". (It is my proud boast to have written a whole book without a single " very " except twice in quotations; but in the present work I have indulged in several.)

Good prose, moreover, should have a swing about it. Ugliness or lack of euphony such as several adverbs or several final *s*'s in succession tires the reader's mind and is a handicap to clarity. A practical test is whether the sentence can be read aloud rapidly without spluttering—compare, in this respect, the second sentence of this paragraph, or the sentence—" The process is one which possesses advantages in certain circumstances "—with any sentence

in the works of the writers named at the end of this section.

All these criticisms may be summed up in a golden rule : *be conscious* of the words and phrases you are using—take an interest in them, worry about them—and acquire a habit of verbal fastidiousness. Why, for instance, do anomalies " glare " ? May one begin a sentence with a conjunction or end with a preposition ? Can something be true " under " the circumstances or only " in " them ? How far is it desirable to use nouns as adjectives in such formations as " oxidation resistance ", " consumer preference ", " organisation methods " ? Can the possessive " whose " be applied to inanimate objects or only to persons ? Is there any sense in saying " a certain number " when you mean " an uncertain number " ? Is there really any objection to split infinitives ?

Refer constantly to a good dictionary such as *The Concise Oxford Dictionary* and read those witty, entertaining and instructive books, H. W. Fowler's *Modern English Usage* (Oxford : Clarendon Press, reprinted 1934) : Professor Sir Arthur Quiller-Couch : *On the Art of Writing* (Cambridge University Press, 1928) ; A. P. Herbert : *What a Word* (London : Methuen, 1935). But when all is said, literary style remains largely a subconscious process ; if, therefore, your work compels you to read much that is slipshod take care to counteract this with liberal doses of such writers as Stevenson, Ruskin, John Stuart Mill, G. M. Trevelyan or Hilaire Belloc the historians, or whatever master of good English your literary taste may lead you to prefer.

See also T. A. Rickard : *Technical Writing* (London : Chapman and Hall).

DICTATING, TYPEWRITING AND DUPLICATING

In appropriate circumstances there is much to be said for the use of a dictating machine in preference to dictating

to a shorthand writer, for in this way one can work as continuously or as irregularly as one likes at any hour of day or night without regard for anything but one's own convenience ; the machine stops and starts on pressing a button, and one can pause to think and make it repeat passages aloud without being rendered self-conscious by the presence of another person. The most usual type of dictating machine records on wax cylinders which, after transcription, are " shaved " in another machine, and can thus be re-used many times. The discs have the advantage that they can be posted in an envelope to a bureau which transcribes them under contract—a method which I personally find convenient for technical writing and translating in my own home. Another machine is the Textophone in which the recording is effected by the varying magnetisation of a steel wire which is wound between the poles of an electromagnet connected in circuit with a microphone ; this machine serves not only for dictation but also for the recording of telephone conversations and conference proceedings. In such work the transcript typed out by the typist listening to the record placed in her own machine is best regarded as a rough draft on which the author can conveniently superimpose not only his corrections but his improvements and second thoughts before having it re-typed as a fair copy ; even so, much time and effort is saved by comparison with using the typewriter oneself, though for some purposes the latter is preferable.

Typewriter keyboards are standardised as regards the arrangement of the letters but not as regards that of the signs and figures, and when buying a machine to be used for technical work it is worth while giving some thought to the latter in the interests of convenience and therefore of speed and accuracy. Special subjects may call for special

symbols ; thus in structural engineering it is well to have a type for ℓ which will not be confused with the figure 1, and in typing algebra it should not be necessary to use x for $\times$. The provision of a type for $\surd$ makes for tidiness. When typing tabulated figures nothing upsets the rhythm so much as having to change shift in order to use the small l for figure 1 or the capital O for zero; to avoid this all ten digits as well as the decimal point and all five arithmetical signs = + × − : (and, with advantage, a vertical line | for separating columns of figures without having to rule such lines by hand) should be on the same bank of keys. Instead of wasting keys on the provision of a great variety of rarely used fractions, small raised figures can be fitted which will serve not only as numerators of fractions but also for mathematical powers and for chemical formulæ if written in the French fashion, as H^2SO^3. Given these, it is not then essential to have separate types for the denominators of fractions like $/_3$ $/_4$ $/_8$ as ordinary figures preceded by the oblique stroke will do, e.g. / 3 / 4 / 8. If French accents are required they can be on a " dead " key which allows them to be printed by a separate motion over any desired vowel without moving the carriage.

Ordinary models of typewriters have 84 types but there is one British make which provides 96 (purchasers being allowed to make their own selection of special signs without extra charge) and there is a new Continental typewriter intended for the production of printer's copy (whether for composition or for photo-lithography) which has 135 characters on 45 keys, including all mathematical signs and many Greek capitals and smalls. These are type-bar machines adapted to high speeds, but where speed is secondary and variety of types is the main consideration that object can be obtained more cheaply in a machine which

works on the type-wheel principle. With such a machine, alternative founts of type can be obtained in a few seconds by changing the wheel.

Up to half a dozen tolerable copies can be typed at once using the proper grade of carbon paper.

The cheapest form of apparatus for obtaining a larger number of copies—up to about 50—is the hectograph. The original document, typewritten with a special ribbon or carbon paper or drawn with a copying pencil or pen using hectographic ink, is transferred by pressure on to the surface of a gelatine pad, and copies are made by pressing successive sheets of paper on to the pad.

Far superior results are secured with the Ormig machine which will print up to 200 perfect copies. The original is typewritten (or is drawn, ruled or written with an ordinary pencil) on art paper over a special kind of carbon paper which produces a mirror copy on the back, and the printing is done directly from this without the intervention of a "jelly". The colour of the carbon paper can be changed as often as desired while preparing the original and in this way prints made up of up to four different colours (not, however, including black) can be obtained in the one operation.

The usual method, apart from the above, of making multiple copies of typewritten matter or line diagrams—up to many hundreds if required—is that for which the correct generic name is the mimeograph, wherein the typewriter (without a ribbon) or a hand stylus is used to cut out the shapes of the letters and lines in waxed paper stencils and these are placed in a machine which prints by forcing ink through them from behind.[1] The required number of

[1] For comparisons of most of these and some other methods see A. Parker: Duplicating—a survey of modern methods. *Rept. 6th Conf. ASLIB*, 1929, pp. 38–55. See also the book by Arkin and Colton quoted on page 287.

copies of each page has, of course, to be run off separately, and in the case of a report of many pages the most troublesome part of the job—needing plenty of table space and giving rise to risk of mistakes if done in a hurry—is that of sorting out the pages into batches. Another nuisance is that if one is uncertain how many copies of the complete document may eventually be needed one is compelled either to print an excess which will probably be wasted or to risk having to put each stencil into the machine again for the sake of only a few extra copies. It may be suggested that what is needed is a machine like a giant addressing-machine which instead of duplicating one page at a time would run through a stack of flat stencils, printing one copy at a time of all the pages in sequence, and so avoiding the need for a separate sorting operation.

In the multilith or Rotaprint process the original is typewritten (using a special ribbon, and with types absolutely free from any trace of ordinary ink) or is drawn with a pencil, crayon or brush on to a flexible zinc plate; alternatively the original document may be photographed on to a paper film against a ground-glass background in a photostat camera and the developed film "burned" on to the zinc plate by arc-light. The copies are obtained indirectly from the zinc plate by a process similar to offset printing, using an automatic machine which costs £200–300 and will print at a rate of 1,500 to 6,000 copies an hour up to about 10,000 impressions from the one plate. The process depends on the fact that the image on the plate is formed in a greasy substance to which the greasy lithographic ink will adhere, whereas the rest of the plate, being moistened with water, repels the greasy ink. The ink image is transferred from the zinc plate on to a rubber "blanket" whence, in turn, it is imprinted on the sheets of paper.

PHOTOGRAPHIC REPRODUCTION

Photography, using the term in its widest sense, calls for mention here—

(*a*) As a means of retaining copies of documents for purposes of collative research when the originals are only temporarily available or are not in a convenient form for filing. This has been mentioned on page 229 as an alternative to writing notes by hand which is laborious, or to dictating them which involves risk of inaccuracies. It can be done by either Photostat or reflection copying as described below or by microphotography which is the subject of the next section.

(*b*) As a direct means of multiplying documents for limited circulation. This can be done cheaply by contact printing if the originals are transparent or translucent, or more expensively by any of the other methods described below if the originals are opaque.

(*c*) As a preliminary to lithographic methods of printing such as the Rotaprint already described. These are the only means whereby pictorial matter can economically be reproduced in a large number of copies. Moreover, they are cheaper, in certain cases, than printing from type; as, for instance, where it is required to reproduce an out-of-print book (amendments being readily introduced by pasting them over the original text before photographing). 70 per cent of the cost of setting up tabular matter in type can be saved by adopting the alternative of photographing a typewritten or hand-lettered copy of such matter and using a reduced photographic copy thereof for offset printing.[1]

Photographic methods applicable to these purposes may

[1] N. Parley: Facsimile processes, with special relation to tabular matter. *Rept. 10th Conf. ASLIB*, 1933, pp. 33–4 and 9 pages of specimens.

be divided into contact printing, reflection copying and methods involving the use of a camera with a lens.

Contact-printing methods are much the cheapest but can be applied only to line as distinct from half-tone originals, i.e. not to pictures containing tones intermediate between black and white, apart from shading which can be shown by line or stipple.

With a view to contact printing the master copies of engineering drawings are usually made on tracing cloth. Since this material is expensive whereas tracing paper is cheap it is worth noting that the main disadvantage of the latter, the fact that its edges easily tear, can be overcome by the use of a small machine costing a few shillings which strengthens the edges by framing them in a gummed linen strip.

Negatives for contact printing can be made in a Photostat camera, described below, by substituting a special transparent sensitised paper for the opaque printing paper normally used therein. The use of these is cheaper than repeatedly photostating the original if more than a small number of copies is required. Satisfactory contact prints can be obtained also from ordinary typescript or manuscript provided the paper is not unduly thick and bears no watermark, and still better ones if a piece of ordinary carbon paper has been placed underneath it, black side up, while typing or pencilling. For a small number of copies this is a cheaper method of reproduction than the use of wax stencils, and it is useful also when copies of existing documents are unexpectedly required. Tabular data are especially difficult to typewrite as the column headings tend to become overcrowded; a better and quicker way is to print them by hand in drawing-office style on transparent paper printed with feint squares, which make it easy to rule the columns and preserve

alignment but do not themselves reproduce in the contact prints.

Contact printing may be done in a simple daylight printing frame which has a capacity of about 200 prints a day ; in a semi-automatic machine with an ultra-violet lamp printing up to 500 copies a day ; or in one of the elaborate modern plants producing up to six times as many in which the negative and the printing paper (which may be of unlimited length) merely have to be fed into the rollers at the entrance to the machine. The occasional user, rather than maintain his own apparatus for the purpose, will find it economical to have such work done for him by one of the photo-printing firms which undertake to collect and return it within a few hours. The varieties of contact printing include the following :[1]

(1) Blueprinting by the ferro-prussiate process. This is the cheapest method (3*d.* a copy foolscap and 6*d.* demy, i.e. 22 inch by 15 inch size, whatever the number of copies) but the appearance of white lines on a blue ground is for some purposes objectionable and any pencil or ordinary ink marks which it may be desired to make on the prints do not show up well. Special " correcting ink " is, however, obtainable for this purpose.

(2) Ferro-gallic printing gives dark purple lines on almost white background, but is slower and liable to reproduce badly from a worn tracing. (6*d.* foolscap, 1*s.* 2*d.* demy, whatever the number of copies.)

(3) Dyeline and sepia printing are now generally considered the most satisfactory of these processes. Drying is

[1] G. T. Clarkson : The preparation and reproduction of illustrations for technical reports. *Rept. 10th Conf. ASLIB*, 1933, pp. 45–55, compares the scope and advantages of the various methods and briefly explains the chemistry involved.

rapid and a wide range of colours can be obtained including a close approach to pure black. Using the diazo process, development takes place dry by exposure to ammonia vapour.

What is usually referred to as "true to scale" is not a contact but a transfer process, making use of a jelly, which produces clear black prints on any paper or on opaque or transparent cloth. The 1946 list prices for such prints are—

	Foolscap.	*Demy.*
On thin drawing paper :		
First copy	1*s.* 2*d.*	1*s.* 10*d.*
Extra copies	6*d.*	11*d.*
On thick drawing paper :		
First copy	1*s.* 6*d.*	2*s.* 5*d.*
Extra copies	10*d.*	1*s.* 4*d.*
On cloth :		
First copy	2*s.* 4*d.*	3*s.* 8*d.*
Extra copies	1*s.* 8*d.*	2*s.* 7*d.*

Reflection copying [1] makes use of a different principle : in the Ruthurstat and Rectophot apparatus paper is pressed into contact with the document to be copied, this paper having been so treated that light can pass through it and be reflected back from the document on to a sensitive layer of silver bromide at the surface, the difference in the amount reflected from the dark and light portions of the document

[1] S. C. Bradford : Documentary photography and research. *Nature*, 11 March 1939, pp. 393–4. Another article, S. C. Duty : Reflection copying, *Journal of Documentary Reproduction* (Washington), Sept. 1941, pp. 177–82, describes an inexpensive home-made apparatus "smaller than a portable typewriter", in which it is claimed that 9 in. × 6 in. sheets can be copied at a material cost of 2 cents per page.

producing a negative photographic image from which contact prints can afterwards be taken. The Retocee process, more recently introduced, makes use of thin transparent cellulose sheets coated on one side with a diazo compound; after exposure under an arc-light mechanised treatment with a suitable solution immediately develops a full-sized positive image through the formation of a dyestuff. This dries instantaneously and is made ready for delivery by pressing the tissue on to a sheet of tacky white paper to show up the image. The whole operation takes about three minutes and can be performed by anyone in broad daylight at low cost.

The Photostat apparatus resembles a large ordinary camera with its axis horizontal, but the place of the usual lens is taken by a prism which serves the double purpose of allowing the object to be photographed to be laid on a horizontal table below the front of the camera instead of having to be held vertically, and of correcting the lateral inversion of the image. The latter is thrown directly on to sensitised paper in a continuous roll like the spool of film in a pocket camera, and after each exposure a handle is turned to wind the exposed length of paper out of the camera into a developing bath where it is cut off with a guillotine. The image so produced and fixed is "negative" in the sense of being white lines on black ground, but because of the prism the image is the right way round—not mirror writing—and for most practical purposes is as good as the original without further processing; if, however, black lines and lettering on a white ground are essential this can be achieved simply by re-photostating the negative which is first obtained. Ordinary daylight can be used but mercury vapour light is recommended. Photostat copies may be made either the same size as the original or may be enlarged

or reduced in the process of exposure. The cost of the machine is £215 upward according to size; many duplicating offices and photo-printers (as well as Photostat Ltd. themselves) undertake copy work for the public, the price for the first copy varying from 9*d.* for not above 11½ inches by 6½ inches to 9*s.* 8*d.* for not above 44 inches by 30 inches. In the smaller sizes additional copies (made by re-photostating each time) are only slightly cheaper than the first copy; even in the larger sizes they cost about two-thirds as much and the process as described above is not, therefore, an economical one where large numbers are involved, but as already mentioned it can be used to make negatives for contact printing.

MICROPHOTOGRAPHY

The possibility, now realised millions of times daily, of securing reproducible images either of loose documents or of the pages of bound books on photographic film, reduced to a minute fraction of the original size, may well mark the most revolutionary advance that has occurred in documentation since the invention of printing.

The limit to the degree of reduction obtainable in this way is set by the "grain" of the emulsion on the film. Promising experiments on "grainless" emulsions are in hand which if successful will mean the removal of any limit until molecular dimensions are reached; meanwhile a reduction ratio of 60 diameters is within the bounds of possibility and this would enable 500 pages of a large book to be reproduced on a single 5 inch by 3 inch film for filing like a card index; a single drawerful of such records could contain in miniature a dozen copies of the complete *Encyclopædia Britannica.*

Special forms of camera, masks and projection reader

have been described,[1] enabling micro-images the size of a postage stamp to be arranged in rows on " cards " which can be stored and indexed in the ordinary way. Each such card contains eight rows of twelve such images, making a total of 96.

Though the keeping of literature in the form of a roll is a reversion to the library methods of many centuries ago and will probably give way sooner or later to the use of flat micro-records, it is convenient and economical at present to use spools of the standard 35 millimetre or sub-standard 16 millimetre (non-inflammable) cinematograph film, and several makes of camera are on the market which will photograph documents up to newspaper size on one or other of these. Thus the commercial model " Recordak " made by Kodak Ltd. automatically photographs cheques or similar loose papers as fast as the operator can throw them into the machine, which is at the rate of about 5,000 an hour, and one of the City banks photographs up to 200,000 cheques a day by this method. Another model photographs bound volumes of newspapers, the camera moving to and fro so as to cover the alternate pages as they are turned over. For smaller working capacities several of the high-grade portable cameras can be adapted to this use, held vertically on a folding tripod or on a frame which defines the edges of the field of print to be photographed. A researcher visiting a library can bring such a camera with him and take away photographic records instead of laboriously copying out notes.[2]

[1] J. A. Reyniers and others : The use of flat film for microphotography. *Journ. of Documentary Reprodn.* (Washington), March 1941, pp. 3–8.

[2] Such a camera costs £30–40. An ingenious amateur with a workshop might be able to build one much cheaper from scrap material on the lines of the wooden box camera with self-contained electric-lighting system and " vest-pocket " size film spool for photographing × 5 enlargements of labora-

The space required for storing microfilms is about 1 per cent of that needed for the original documents.

The negatives so produced can be used in several ways. They may be enlarged upon paper, giving prints that take the place of photostats, or upon standard lantern slides for lecture purposes. Alternatively the spools or strips of film (either the negative or a contact print made from it) may be placed in a " reading machine " which stands on the table and throws a life-size or slightly larger image of the original documents on a screen in a convenient position for reading. Monocular " viewers " costing only a few shillings are also available, which are satisfactory for purposes of inspection but are not intended for continuous reading.

The following extracts from a paper [1] by the director of the American service mentioned therein will serve to illustrate the importance of microphotography in technical documentation :

> Most immediate and practical to put into operation is the microfilming of material in libraries upon demand. It will become fashionable and economical to send a potential book borrower a little strip of microfilm for his permanent possession instead of the book and then badgering him to return it before he has had a chance to use it effectively. I believe that reading machines for microfilm will become as common as typewriters in studies and laboratories. If the principal libraries and information centres of the world will co-operate in such " bibliofilm services ", as they

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tory specimens, constructed for less than £3 and described in Technical Paper No. 111 (*A Portable Low-Power Micro-Camera*) of the Research Association of British Paint, Colour and Varnish Manufacturers.

[1] Watson Davis : The uses of microphotographic processes in documentation. *Rept. 14th Conf. ASLIB*, 1937, pp. 100–7, with discussion and list of exhibits of microphotographic equipment. The same Report contains an informative introduction to the subject by Professor R. S. Hutton giving particulars of various apparatus and a photograph of the " Newspaper Recordak ".

are called, if they exchange orders and have essentially uniform methods, forms for ordering, standard microfilm format and production methods and comparable if not uniform prices, the resources of any library will be placed at the disposal of any scholar or scientist anywhere in the world. All the libraries co-operating will merge into one world library without loss of identity or individuality. The world's documentation will become available to even the most isolated and individualistic scholar. . . .

The microfilm can be used to secure what can be called " auxiliary publication ". It will supplement other forms of publication and make accessible material of all sorts that can not now be printed because of economic factors. It will make available valuable research data that now go unrecorded. It will make available out-of-print and rare books. . . .

This idea has been given an experimental demonstration in America in connection principally with scientific papers. There a journal editor can publish as much or as little of a technical paper as he wishes. In the case of a very specialised paper it may be only an abstract or summary. He appends to the notice or article a note saying that the full article with diagrams, pictures, etc., can be obtained by remitting a certain price and specifying the document number under which this full article has been deposited at the central agency operating the auxiliary publication service. Microfilms of the document are made only if and when ordered. In this way the document is perpetually " in print " but no extensive, space-consuming stocks need be stored, only the document itself and the microfilm negative from which positives are made for distribution.

Another documentation project of importance to the world is much more formidable and can not be accomplished without much planning, development and international co-operation.

It is possible to visualise the creation in some world centre of a card file with a card for every article, paper, book or document published in science that is important to the written record of science. Each card could be given multiple classifications. Now if for each of these classifications the card were microfilmed, with a pattern representing that classification, and if selection from microfilm is developed so that a roll of microfilm is run through

a selector which prints only microfilm bearing a predetermined classification pattern, we shall have the mechanism whereby a great world file of bibliography can be made to produce special bibliographies in any subject to order. And this should be done at a cost that would allow its use by every scientific research worker.

The address of the central agency for " auxiliary publication " on these lines is

American Documentation Institute,
care Offices of Science Service,
2101, Constitution Avenue,
Washington, D.C.

and the address of the non-profit-making organisation which will supply microfilm copies of any specified extracts from books or journals in a great range of libraries covering most branches of science is

Bibliofilm Service,
care U.S. Department of Agriculture Library,
Washington, D.C.

Such copying is done at cost, the rates being a fixed charge of 20 cents for each order plus 1 cent per page copied. " The service is not offered to the general public, but is available to anyone doing research. No current publication is copied, and the gentlemen's agreement between the publishers' and scholars' organisations is lived up to." (These particulars are taken from a letter in which permission is kindly given me to quote the long extract above.)

Another idea from America is put forward by Fremont Rider in his book *The Scholar and the Future of the Research Library: a problem and its solution* (New York, 1944). He shows that in the United States such libraries double their size roughly every 16 years, demanding ever more space and entailing ever greater delays in access to the books. His

suggested remedy is to catalogue the books in the ordinary way on 5 in. × 3 in. index cards, the backs of which would be sensitised and contain rows of tiny microphotographs of the complete text of the book itself, up to 500 pages on a single card. By means of apparatus installed alongside the index readers would be supplied on demand, at small cost and with only a few minutes' delay, with copies of any such micro-cards as they might prefer to take away with them to read through their own enlarging viewers.

Since 1936 the American Library Association has published an annual handbook, *Microphotography for Libraries*, containing a review of developments and lists of services utilising this device. The subject is also dealt with in the quarterly *Journal of Documentary Reproduction* (Washington).

In this country ASLIB is much interested in the subject. The beginnings of a microfilm service, which has already done valuable work, were organised by it in 1942. A conference on this and other means of documentary reproduction was held in June 1945, and articles thereon will appear from time to time in the *Journal of Documentation*.

An issue which will have to be faced—and the sooner it is settled the better—is that microphotography, to the extent that it replaces the distribution of printed publications, cuts straight across the way that authors and publishers are at present remunerated for their services. What the solution may be it would be rash to predict; perhaps some sort of royalty payments similar to those for musical performances. Meanwhile it appears to be held that copyright is not infringed if photographs are taken of published texts purely for purposes of one's own research (but I accept no legal responsibility for this opinion).

PRINTERS AND PUBLISHERS

The methods of reproduction described above are suitable mainly for documents which are to be given a limited or internal circulation. Publication in the wider sense is a business conducted by specialists and beyond the scope of this book, but one about which a writer needs to know enough to regulate his relations with publishers and printers. Some advice on how to obtain such knowledge may be useful here, and from this point of view the media for technical publications falls into three main classes :

(1) Papers presented to societies and institutions as already mentioned here on pages 36 and 141. In most cases the authors are members of the organisations in question but the offer of suitable papers by others is welcomed. No payment is made but the author adds to his professional reputation in this way and sometimes there are prizes for the best papers. Guidance as to the required form and length of manuscript and illustrations, and sometimes suggestions as to subjects on which contributions would be opportune, may usually be obtained from the institution concerned. To quote from the pamphlet issued with this object by the Institution of Civil Engineers, " authors can often, at little or no additional cost or trouble to themselves, reduce to a considerable extent the expense and time involved in printing " by observing certain details of procedure as detailed therein, and this expense, considered in relation to the value and originality of the paper, is naturally one of the factors influencing the decision whether it can be accepted for publication. In most institutions such decision is in the hands of a committee for that purpose which meets, as a rule, once a month during the session. It is a usual requirement

that a paper shall be submitted in a complete and definitive form, ready for the printer, and accompanied by an abstract of its contents. Anything that savours of commercial advertisement (even the use of trade names) is barred.

(2) Articles for independent journals. Some of the latter are filled almost entirely by staff writers or regular contributors but others rely to a varying extent on manuscripts sent to them from outside, and it is thus open for anyone who can make a good impression with his work to gain a footing which may lead to his being asked to contribute on a future occasion, should the subjects in which he is interested become topical. In this connection the important thing is to convince the editor of one's readiness to produce, without delay, the exact kind and length of article that he asks for. In the case of an unsolicited manuscript a stamped and addressed envelope for its return should always be enclosed, and there is no cause to be downhearted until the article has been rejected in turn by every one of the journals in the considerable list it is possible to compile relating to any given field of knowledge (not forgetting journals published in the Dominions), for it is to be remembered that the acceptability of an article depends not only on its intrinsic value but also on whether the editor needs an article on that particular subject at that particular time. The rate of payment varies, for technical matter, up to several pounds per thousand words, but seldom reaches a high rate per man-hour of labour expended in research, thinking, drafting, typing and correcting. Payment is never made before publication and often not till the end of the month after. The *Writer's and Artist's Year Book* (London: Black) gives useful information including the addresses of journals and notes on each of these.

(3) Books. A representative selection of publishers of

technical books will be found in the *ASLIB Book List.* Some obtain the greater number of their manuscripts by commissioning known experts to write on subjects which the publishers, with their fingers on the pulse of the trade, know to be needed, but all are willing to consider manuscripts sent to them on the initiative of authors whether previously known to them or not. The market for technical books, being restricted in proportion to the degree of specialisation of the subject matter, is even more difficult to deal in than that of other books. An admirably informative manual on the whole subject exists in Sir Stanley Unwin's *The Truth About Publishing* (London: Allen & Unwin, 1926[1]) which has chapters describing the routine followed by publishers in dealing with manuscripts submitted for consideration; the relations between publisher and printer; the factors that govern prices of books ("If a publication is to be economically self-supporting, the published price must usually be fixed at not less than three times the cost of production"); the various forms of agreement in vogue between author and publisher (outright sale, profit-sharing, royalty and commission); the things that an author should know about printing, bookselling and copyright; and many other matters.[2] Mention should be made also of the little

[1] New edition, 1946.

[2] One of Sir Stanley's incidental points may well be quoted here: "When a library is started, no one thinks of asking Maples to give the furniture and Catesbys to give the linoleum, but it often seems to be considered quite in order to try to cadge books from publishers. . . . Learned societies and similar institutions seem to me especial offenders, both because they exist presumably to promote the study of the subject in which they are interested, and because they ought to know better. So far from encouraging the publication of learned works by the purchase of copies, they seem with one accord to devise means of securing gratis even the one copy required for their own library"—as by claiming for it the review copies sent to their journal. "A German publisher of a first-rate learned work knows that all

book by F. Howard Collins : *Authors' and Printers' Dictionary* (London : Humphrey Milford, 7th edn., 1933), described as " a guide for authors, editors, printers, correctors of the press, compositors and typists ; with full list of abbreviations ; an attempt to codify the best typographical practices of the present day " and containing, in addition to the dictionary proper, many useful hints in an article entitled " Author and Printer ".

Both these writers lay stress on the importance and ultimate economy of going to trouble in preparing a perfect and consistent typescript, even if it means recopying several times, typewriting being always a much less costly and laborious operation than those of setting and altering printer's type. A typist, it is urged, should follow some definite " Rule of the House " as a book printer does in order to preserve uniformity in such matters as punctuation, the spelling of proper names and use of capital letters, the questions of " -ize " or " -ise ", and of whether titles of publications quoted in text or footnotes shall be in italics or " roman quoted ", and so forth.

There can be little doubt that careful typewriting not only assists the printer but also subconsciously influences those whose business it is to appraise the value of a paper offered for publication. A detail worthy of attention is that of not allowing the ribbon to grow too faint before renewing it ; the cost of such renewal, per thousand words, is negligible but the effect on the reader of not renewing it probably is not so.

For guidance on the important matter of proof reading see the above-mentioned works. It is extremely difficult to

institutions interested in the subject will buy copies ; the British publisher realises (alas !) that he will be expected to donate them " and may easily be faced with a loss instead of say £50 worth of orders for a book, in consequence.

detect minor misprints in a text one has written oneself as the eye refuses to notice every individual letter when the brain already knows the sense of what is coming. Another person can usually do it better, but where perfect accuracy is vital the only safe way of ensuring it is the tedious one of reading the text backwards.

The title for a book, paper or report calls for careful compromise between brevity and descriptiveness since otherwise the hurried peruser may be left unaware of contents which might be valuable to him, and cataloguers as distinct from analytical indexers cannot be counted upon to note bibliographical details other than those printed on the title-page. (How, for instance, are people concerned with translating to be made aware that this book contains a chapter which may interest them?) In cases of difficulty a way out may be found in the provision of a short handy title together with a longer and more descriptive sub-title. On the other hand needless verbosity such as " Notes on . . ." or " Some considerations relating to . . ." is to be avoided.

CHAPTER NINE

FOREIGN LANGUAGES AND THEIR TRANSLATION

INTRODUCTION

TECHNICAL publications on any given subject are potentially of equal value to all the technicians concerned throughout the world, but the realisation of this value is hindered by the fact that such publications are divided into many languages—the *Engineering Index* covers over 20—whilst engineering correspondence, administration and conversation are conducted in many more.

Professor Bernal [76.1], referring to research rather than to the applications of science, has an interesting section on the matter in which he distinguishes four chief " circles of scientific intercommunication " in order of importance as the Anglo-American, the German, the French and the Russian. These " circles " are much wider than national boundaries : the first mentioned, for instance, covers not only the British Empire and the United States but also partially Scandinavia, the Netherlands, China and Japan, and " the German circle is, or was, far more closely knit than the others. Inside it there was not only an exchange of information but also a very considerable freedom of personal movement so that professorships could be given indiscriminately inside or outside Germany to any citizen of the nations in the circle. These included not only Germany and Austria but most of Scandinavia, Switzerland and other central European countries." The French circle, he says,

was once predominant in science but is now much shrunk in relative importance ; whereas the Russian (or, as he prefers to call it, Soviet) circle is a recent development to which he attaches great and growing importance. (On Soviet science, see page 194.)

The existence of these " circles " mitigates but is far from overcoming the curse of Babel, for in the first place not all technicians understand English, German and French (to say nothing of Russian) and only a small fraction of the literature is translated from one to the others of these principal languages, and in the second place great masses of technical knowledge, especially of the more practical kinds, are daily buried from the outside world in the extensive native technical literatures of such countries as Japan, Italy, Poland and others which are active in scientific and engineering work but whose national languages lie outside the " circles ". (Professor Bernal wrote this, of course, before the war.)

The problem of finding a remedy for this state of affairs is best considered separately in relation to what are really two different things : (*a*) the ensuring of awareness of the existence of items of knowledge, no matter what the language of the original publication, by making abstracts, bibliographies and indexes of them available in a language the technician concerned is able to read, and (*b*) the expression of the knowledge itself in a language he is able to read.

Provision as regards (*a*) has already been discussed in Chapter Six and in the first part of Chapter Seven. Provision for (*b*) is at present unorganised, haphazard and fragmentary. The difficulties (discussed below) of technical translating, and the consequent expense, are formidable obstacles to an improvement in these conditions ; but they would be reduced by two-thirds if it could be regarded as

part of the normal qualifications of every technician to be able to read English, German and French so that publications originating in other languages would be rendereduniversally accessible by translation into any one of these three.

There are those who believe that English is destined to become accepted as the universal medium of expression for any scientific ideas to which international importance is attached, and others who advocate for this purpose—as well as for abstracting and for the verbal discussions at international conferences—an artificial international auxiliary language designed so as to be easily and rapidly learned by everyone. Over 200 such languages have in fact been devised, including Esperanto [1] which claims 500,000 users or at least adherents, Ido which is a reformed Esperanto, and Basic English which is ordinary English with a scientifically limited vocabulary to facilitate its writing by foreigners.[2] These proposals may

[1] D. R. Duncan: The use of Esperanto for scientific purposes. *The Scientific Worker*, Feb. 1938, pp. 22–4, claims that an economy of over 50 per cent in the expenses both of the abstracting bodies and of the journal-purchasing public could be effected if any one language could be adopted as a common language for scientific abstracts. Esperanto is already so used in a number of scientific journals, especially in Japan. "Mi konkludas"—he writes—"per paragrafo en Esperanto. Esperanto prezentas al la scienca mondo la sole efektivan solvon de la lingva problemo. La lingvo estas logike konstruita el internaciaj elementoj, kombinitaj en harmonia maniero, facile lernebla de neinstruita homo kaj komprenata sen studo de bone edukita persono. La praktika merito de Esperanto estas nedisputebla." The British Esperanto Association, Inc., conducts propaganda.

[2] By substituting "go up" for "rise" or "ascend", and so on, only 18 verbs are needed instead of the 4,000 commonly in use, and only 850 words of all kinds instead of 20,000. Basic English reads as good, simple English with a pleasant, slightly biblical flavour. Its advocates are fond of writing articles in which they do not tell you till the end that you have been reading Basic English all the time. *Basic for Science* (London: Kegan Paul, 1944) may be of interest. The organisation concerned is the Orthological Institute. With the assistance of the latter, the British Standard Specification for Portland Cement has been translated, and is available in Basic English.

present some theoretical attraction but, except the last, show little sign of overcoming the inertia and acquiring the impetus that might bring about their general acceptance.

ON LEARNING LANGUAGES

In my opinion Englishmen are not, as commonly supposed, bad linguists : too many are not linguists at all but those who have occasion to become so do it better, on the average, than many other nationalities.

Learning a language is like learning to swim : it is worth while to listen carefully to expert advice on the principles involved and to make one's first attempts under supervision, but once that stage is passed and one is not completely helpless the important thing is to take every opportunity of jumping in and trying on one's own account. In the case of a language the preparation may be by way of lessons or self study, aided if possible by gramophone records, and the practice by constant reading. Here the technical man has an advantage : for once the rudiments of the language have been mastered it is in fact easier to read technical subject matter about which one has specialised knowledge, enabling one to guess the meanings of the words from the context (especially if there are illustrations and mathematics or chemical formulæ in it to help), than to read more general texts. One of the best plans for a busy man to adopt is to subscribe to his own copy of a German or French technical journal dealing with his particular line of work (a selection may be found in any good library) ; for whereas a solid book is liable to be put aside, the arrival of a periodical, week by week, and the previous numbers lying about, will provide a recurring stimulus to turning over the pages and reading at least a portion of it. The advertisements, too, may be as instructive as the rest.

Still better, so far as the language and sciences mentioned below are concerned, are the *German-English Terminologies* published by Murby, London (A. King and H. Fromherz : *Chemical* ; R. Jones and A. Cissarz : *Geological* ; H. Ashby, E. Ashby, H. Richter, and J. Bärner : *Botanical* ; E. R. Franz and O. von Auwers : *Physics* ; T. L. Green, J. M. Watson and H. Graupner : *Zoological*). These are textbooks providing a useful kind of refresher course in their respective subjects, with the peculiarity that each paragraph appears on the left-hand page in English and on the right in German, the translation being as close as was found possible without sacrificing literary style. Corresponding technical terms in both languages—of which there are several thousands in each book—are printed in italics on their first appearance in the text and are also collected in an English and a German alphabetical index at the end, so that apart from its primary purpose of developing the reader's power to think about the subject in either language interchangeably the work serves as a dictionary in which each expression is shown in a natural context.

P. F. Wiener : *German for the Scientist* (London : Bell, 1943) contains passages for reading practice in various sciences, with vocabularies and grammatical notes.

There existed in London before the war a useful society known as the Engineer's German Circle which held meetings at which papers on mechanical and other branches of engineering, illustrated by plenty of lantern slides, were presented by visiting German engineers (who were asked to read a little more slowly and carefully than they would in addressing their own countrymen) and were followed by discussion in German with the object mainly of affording practice to beginners in the language. The idea is a useful one, and apart from practice in the language many of the papers were of great interest in themselves.

There is, unfortunately, no corresponding provision for technical French, but the Institut Français du Royaume Uni in South Kensington offers various cultural opportunities in that language.

INTERPRETING AT CONFERENCES

Interpreting at an international technical conference calls for the same qualities as are enumerated below in reference to written translating with the added requirement of ability to think quickly without becoming flustered. It requires, further, a familiarity with the technical terms such as can reasonably be expected only in someone who is or has been professionally engaged himself in the subject matter of the conference.

Two systems are in use. In the first the interpreter takes down notes while listening to the speech in the original language and proceeds, immediately afterwards, to read out his translation in the language or languages required. This has the advantage that it involves no apparatus, but the length of the proceedings is doubled (or trebled if everything has to be translated into two languages in turn) and the repetition is tedious for those members of the audience who have understood the original language.

The other system of interpreting, known as the Filène-Finlay, was developed in connection with the League of Nations. Each member of the audience is provided with headphones which he can plug in (on the back of the seat in front of him) according to the language he prefers, connecting him either through wires or by wireless transmission to a microphone—one for each language—into which an interpreter speaks a translation of what is being spoken simultaneously with listening to it in the original language. The interpreter needs to have the knack of listening in one

language and talking in another (half a sentence or so behind) at the same time, but provided the speed is not too great the feat, while tiring, is not as impossible as it may sound.

This system is, of course, expensive, not only on account of the electrical apparatus but because it necessitates at least one interpreter for each language. In my own opinion, based on experience in interpreting by either system, the latter is to be preferred, subject always to the rule that any statement which it is important to have translated accurately (such as the terms of a resolution) must be submitted in writing beforehand.

PRINCIPLES OF TECHNICAL TRANSLATING[1]

The first principle of good technical translating is to translate ideas and not words. When a competent translator sees the word *Punktschweissmaschine* it should serve to evoke before his mind's eye an image of something which he will then proceed to describe in English as a spot welding machine, but he should not merely equate these terms in the two languages without visualising what they represent. If this is true of a concrete noun it is truer still of abstract and idiomatic parts of speech, for in scientific as distinct from purely literary writing forms of words are not an end but a means—an imperfect means—whereby the writer endeavours to transmit ideas from his mind to other minds. His skill in doing this, even in his own language, bears no necessary relation to the validity or importance of those ideas, and if the original author's expression of them is obscure or otherwise defective it is the translator's duty to disentangle the author's intended meaning and express it in

[1] This and the next two sections are adapted from the paper by J. E. Holmstrom, printed, with a summary of the useful discussion that followed, in *Report 14th Conf. ASLIB*, 1937, pp. 83–95.

the best possible English, trying, if possible, to make the stream rise higher than its source. A technical translator must, therefore, combine three faculties : (1) he must be versed in and able to reason about the subject matter of the translation ; (2) he must be able to read the language he is translating from so well that he can go out to meet the author half-way and apprehend the author's intended meaning even if this is badly expressed ; and finally (3) he must himself be able to embody that meaning in lucid, terse and euphonious English prose. A good translator does not allow the wording of the original to carry forward into the English. In French, for instance, there are so many words (*actuel*, *assurer*, *brutal*, *demande*, *delai*, *éventuel*, *important*, *intéressant*, *prétendre*, *profession*, *revanche*, etc.) similar in form to English words but subtly different in meaning that the chances are against any passage being correctly translatable in this facile way. In German, similarly, there is the word *sogenannte* which an unfastidious translator may render as " so called " without appreciating the slight suggestion which attaches to this English but not to the German word, that the thing in question ought *not* properly to be so called.

The translator's responsibility is, however, a delicate one; for his duty to be untrammelled by the author's wording does not license him to distort by one hair's breadth the author's intended meaning or the author's emphasis. Going further, there arises a question on which I am myself undecided : if the translator is to ignore the word form of the original, while at the same time being scrupulously faithful in regard to meaning and emphasis, how far should he attempt to reproduce the precise intensity of emotional colouring which may be appropriate in the one language and appear odd in another ? Was it right, in translating an Italian paper on structural engineering, to tone down the author's

exuberant *questo magnifico edificio* to some such phrase as " this notable structure " which an English engineer might have used if placed at the author's standpoint ?

Here, perhaps, lies the difference between technical and purely literary translating : the former should aim at a cold objectivity and its reader should be unable to detect what language it has been translated from, whereas in the translation of a French or German novel a subtle suggestion of Frenchness or Germanness in the English rendering may be pleasing and proper.

A duty which provides a real test of technical as distinct from linguistic knowledge is that of translating mathematical symbols which are governed by habits, customs and mnemonic devices current among engineers in each country and, therefore, are not international, so that they may confuse a foreign reader if not transliterated ; hence the translator's job is not complete unless this is done. In reference to reinforced concrete, for instance, the French E_b, E_a meaning *coefficient d'élasticité du béton, de l'acier* should be altered in an English text to E_c, E_s, which will at once be recognised as " modulus of elasticity of concrete, of steel " ; the French A for *allongement* (elongation) should not be left to puzzle an English reader who may think it stands for " area ". Similarly in writing trigonometry the Germans put *tg* where we put " tan ", and instances might be multiplied indefinitely. (On standard symbols see page 289.)

It is obvious, however, that transliterating the mathematical symbols adds so greatly to the labour involved that the translator cannot fairly be expected to do it unless his client appreciates this and is willing to pay accordingly. If this condition is not fulfilled, or if transliterating the symbols in the text would entail expensive amendments to illustrations, or if there is any doubt at all about the efficiency

of the checking and proof reading, it is probably better to leave the mathematics as it stands, merely taking care that the meanings of the foreign symbols are clearly stated and that the little tricks such as the useful German habit of adding the suffix *zul* (meaning *zulässig*) to the symbol which stands for stress, when it is required to denote a " permissible " stress, are suitably explained.

A similar question arises as regards converting metric into British units of measurement. Unless the client is willing to pay for having this carefully done and rigorously checked, it is better not to do it.[1] The necessity for such conversions depends upon the purpose of the paper which is being translated, but as a rule it certainly is more difficult for an English engineer to visualise dimensions expressed in metres, or stresses in kilogrammes per square millimetre, than in units he uses daily. Common sense should be used in deciding how accurately to convert units : if, for instance, a foreign writer says that the water level fluctuates by three metres there is no point in rendering this obviously rough statement as 9 feet 10⅛ inches, when what he means is " about 10 feet ". An example which reveals whether the translator is himself a structural engineer is his knowledge or ignorance of the fact that English engineers are accustomed to think of stress values in steel as so many tons per square inch, but stresses in reinforced concrete as so many pounds per square inch, following the American habit. Other examples might be found in all branches of engineering, and no one should undertake translations outside his own province unless they are to be checked or edited by a specialist therein.

[1] British Standard Specification 350 of 1944, *Conversion Factors and Tables* (96 pages), may be of use and the *Conversion Tables* produced by Gall & Inglis, Edinburgh and London, are arranged in a particularly convenient way. Regarding the avoidance of silly mistakes see page 289 of the present book.

Another moot point is whether or when titles such as *Ingénieur-en-chef des Ponts et Chaussées* or *Regierungsbaumeister* should be translated; some of them are practically untranslatable.

WORKING PROCEDURE IN TRANSLATING

According to Kelly's Directory there are in London altogether 61 established translating bureaux, of which seven state that they do technical work, in addition to a great many secretarial bureaux which advertise incidentally that they undertake translations. My own point of view is that of a private worker who does a great deal of translating in his spare time and is confronted occasionally with the problem of so planning the use of a limited number of hours a day as to yield the greatest possible output of work in a period of some weeks or months.

The maximum number of distinct phases into which it is possible to subdivide the work of translation—assuming that it is desirable to do so—are the following nine:

A. Reading the original.
B. Elucidating any unknown or doubtful words.
C. Drafting the English version.
D. Recording the draft.
E. Correcting the draft.
F. Typing the final copy.
G. Inserting mathematics.
H. Examining the final copy for mistakes.
I. Correcting any such mistakes.

The question for discussion here is the best way to plan each of these operations, either by the translator single-handed or with collaborators, so as to economise effort and maximise output.

It is just possible, indeed, to combine all nine of these

phases in a single operation provided the work is not too difficult; when work has to be done in a great hurry and occasional crossings-out in the fair copy can be tolerated the best plan may be to translate direct from the original on to the typewriter, simply drafting each sentence in one's head before typing it and pausing as necessary to use the dictionary.

As a rule, however, it pays at least to separate the phases A, B, C and D from the phases, E, F, G, H and I; in other words it is best to make a rough draft and have the final copy typed from this after correction. The translator's time is more valuable than that of a typist knowing only English, and it is economical to arrange for the typing to be done by contract or otherwise, rather than to do it oneself if one is busy. The next step in subdividing the work, if it is desired to make one translator's key knowledge cover as large an output as possible in a given time, is to let items G and H be done by a third person (or, alternatively, for them to be done by the typist if she is competent): someone who can read the foreign language (not necessarily as well as the translator himself) may read through the final copy to make sure that nothing has been left out and that any mathematics, bibliographical references, etc., have been correctly copied, marking any mistakes or points on which he is not certain with a soft pencil in the margin, but leaving it to the translator himself to fulfil his responsibility by making the corrections, deciding the doubtful points, and rubbing out the pencil marks. The employment of an assistant to check back against the original is preferable to doing it oneself because, apart from time saved, mistakes or omissions are more likely to be noticed by an independent person. It also affords a means of training translators.

The copying-in of mathematics, item G, may well be

done by someone whose time is less valuable than the translator's provided it is checked by the latter, and if all symbols are thus inserted by hand amid the typewritten text it is a help to the printer who has to set up the symbols in italics.

Let us now revert to the items A, B, C and D : is it possible or expedient for these to be divided up among more than one person ? Clearly it would not be economical to take up two people's time if one could do the job as quickly by himself, but there may be cases where a partnership between one man who is predominantly a linguist, another who acts as the specialist technical consultant, and perhaps even a third person who is better than the first two at composing English, would be the best way of working.

Item C is intended to cover the act of deciding how the ideas are to be expressed in English, and item D the act of putting on record the expressions so decided upon with a view to the later operations which we have already discussed. C and D may be performed by the same person or by two persons, and the following possibilities are open :

(1) If the translator who carries out C is later going to perform operation F by himself, he can scribble down his rough notes as roughly and illegibly as he likes, using whatever abbreviations he chooses, and rely on his memory to interpret them (aided by reference back to the original language if necessary) when he comes to type them out. There is a good deal to be said for this method, because if the translator does his own typing he can, to a great extent, combine F with E. The question really depends on whether he likes typing.

(2) If the translator is able to write shorthand of a kind which the typist is able to read, then this will probably be the best plan to adopt.

(3) Failing either shorthand or willingness to do one's

own typing, the other way is to write out the draft in longhand, which is tedious but straightforward, satisfactory and easy to revise.

(4) The translator may dictate the draft to a shorthand-typist, afterwards correcting her transcript and having it retyped, as already explained. The objection to this is that the translator and the typist must work the same hours, and yet the typist must have time to do her typing.

(5) What I find the best and most economical method in my own case is to record the draft on a dictating machine, as explained on page 296. The actual dictation takes about one-sixth of the time required to write out the draft in longhand, and even allowing for correcting and improving the draft as transcribed before it is finally retyped, the total demand on the time of the translator himself is only about one-half of that otherwise required. Before the war such a machine cost £65, so that allowing 5 per cent interest and 20 per cent depreciation, together with an allowance for the cost of the records, the total came to an average of about a shilling a day. In other words, one need only do a fraction of a page a day more of technical translating at the usual rate of payment for such work in order to cover the cost of a dictating machine, and in return for this one's rate of output is doubled.

TECHNICAL DICTIONARIES

Dictionaries are, of course, indispensable in translating, but they are dangerous, however good, because they entail a risk of the very thing most to be condemned—namely, the mechanical translation of words rather than the operation of the translator's trained mind to express in the one language the same ideas that the author has expressed in the other. To consult an interlingual dictionary is to short-

circuit one's mind, and proficiency in technical translating may be measured by the infrequency with which the translator is obliged to do this : but that is not to say that he should not make constant reference to as many dictionaries as he can find in order to widen and deepen his knowledge.

The most valuable dictionaries and aids are those specifically designed to educate instead of short-circuiting the user's mind by showing not words by themselves but the use of words. The value of Murby's *German-English Terminologies*, from this point of view, has already been mentioned, and another example by the same publisher is the *Lexicon de Stratigraphie—Vol. 1, Africa* (1938) which gives annotated definitions of 1,100 geological terms in English, French, German, Italian and Spanish.

General dictionaries are seldom adequate, by themselves, to the needs of the technical man, but the two large volumes (at 42*s*. and 63*s*.) edited by J. E. Manson : *French and English Dictionary* (London : Harrap, 1939) are rich in up-to-date technical terms and authoritative in other respects.

Inter-lingual technical dictionaries are cited below under three heads according as the arrangement is :

(1) Alphabetical in each language, (2) Directly alphabetical in one language only, or (3) like the last but with illustrations.

(1) Bi-lingual and tri-lingual dictionaries in which the words are arranged in a separate alphabetical order in each " language from " are the quickest kind to use.

One of the best is the *Hoyer-Kreuter Technological Dictionary*, edited by A. Schlomann (Berlin : Springer, 6th ed., 1932), in three volumes (German-English-French, English-German-French, French-German-English) of about 800 pages each, priced at 78 RM. per volume. Its typography is well chosen—a matter of the first importance in such a work—

and its purpose is to provide a technological dictionary which covers a wide field, for general use.

A specialised chemical work arranged in the same way as this, again in three volumes but somewhat larger in size, is A. W. Mayer's *Chemisches Fachwörterbuch* (Leipzig: Otto Spamer, 1929), in which each word is followed by a synonym or explanation.

A smaller chemical dictionary of great merit which gives many physical, biological and metallurgical terms in addition to the strictly chemical and which also embodies a good deal of general vocabulary is A. M. Patterson's *German-English Dictionary for Chemists* (London: Chapman & Hall, 1935, 2nd edn., 411 pages), which also has a companion volume, *French-English*, and an instructive preface on the subject of technical translating.

Another excellent specialised dictionary (but by no means narrowly specialised) is H. Freeman's *English-German and German-English Dictionary for Metallurgists*, in two volumes, 347 and 227 pages respectively (Leipzig: Otto Spamer, 1935), each containing about 32,000 words. These cover many welding terms which are difficult to find elsewhere.

T. E. R. Singer's *German-English Dictionary of Metallurgy* with related material on ores, mining and minerals, crystallography, welding, metal working, metal products and metal chemistry (New York: McGraw-Hill, 1945) has 298 pages and costs 24*s*.

A. Aumuller's *New English-Portuguese Technical and Chemical Dictionary* (Rio de Janeiro, 1941) is a work of 341 pages. L. A. Robb's *Engineer's Dictionary, Spanish-English and English-Spanish* (New York: Wiley and London: Chapman & Hall, 1944) has 423 pages.

Several dictionaries are published by Routledge, London, including J. O. Kettridge's *French-English Technical Dictionary*

(1925), A. Webel's *German-English Technical and Scientific Dictionary* (1930) and R. L. Guinle's *Modern Spanish-English and English-Spanish Technical and Engineering Dictionary.*

A specialised English-Spanish and Spanish-English work is A. J. R. V. Garcia's *Dictionary of Railway Terms* (New York: Van Norstrand, 1912). The American Road Builders' Association, Washington, issued in 1932 a mimeographed list of 2,000 words and phrases under the title *Highway Nomenclature*, English-Spanish.

B. R. Durfeld's *Auto-Dictionaer: Deutsch-Französisch-Englisch* (Berlin: Nanck & Co.) gives 16,000 automobile terms.

A. Bray: *Russian-English Scientific Technical Dictionary* (New York: International Press, 1945) is now advertised in London at 50*s*.

As regards Polish, Part I, English-Polish-French-German of a *Technical Dictionary in Four Languages* (Warsaw: Ksiegarnia Techniczna, 1937; 487 pages, about 18*s*.) may be mentioned.

Concrete Publications Ltd., London, reprinted in pamphlet form in 1935 the *International Dictionary of Cement*, English-French-German-Spanish, which had appeared by instalments in the journal *Cement and Cement Manufacture* beginning March 1933. Another small dictionary on cement and lime as between English, French and German is M. Bugnon's *Vocabulaire du Ciment et de la Chaux* (Paris, Revue des Mat. de Cons., 1936).

I.C.I. Ltd. (Dyestuffs Division) have produced a 27-page *German-English Vocabulary of Technical Terms used in connection with Rubber.*

British Chemicals and their Manufacturers, the annual official directory of the Association of British Chemical Manufac-

turers, contains the French, Spanish, Italian, Portuguese and German names of about 1,500 products arranged alphabetically in English but without indexes in the other languages; also the chemical descriptions in all six languages of nearly as many products again which are listed under proprietary and trade names or trade marks. The names of the manufacturers of each item are also given.

(2) Another type of dictionary is that in which the corresponding expressions in many languages are printed in parallel columns, so that a single volume (or succession of volumes) serves for translating from any one of these languages into any other. The sequence being alphabetical in only one of the languages it is necessary when working from any of the others to refer first of all to a separate index giving the page number where the required word will be found in the dictionary itself. Having to make this double reference is, of course, a disadvantage—especially in the case of words which occur several times over in different parts of the book, so that the reader may be obliged to turn them up in turn before discovering the particular context he wants —but in some dictionaries of this type reference is made quicker by the index giving not only the page number but also the position on the page where a word will be found. The advantage lies in the fact that, for instance, a six-language dictionary on this plan takes the place of 30 bilingual dictionaries.

Pitman's *Technical Dictionary of Engineering and Industrial Science in Seven Languages* (English, French, Spanish, Italian, Portuguese, Russian and German) is of this type. It consists of five volumes (costing £8 8*s.* in all), one containing the indexes in the various languages and the other four the translations of the terms in alphabetical order in English (hence the dictionary is much quicker to use from than into

English). The arrangement is continuous, not subdivided into branches of engineering because, to quote the preface, "it was found that about sixty per cent of any such special lists must consist of more or less general engineering terms, and that just about forty per cent would be peculiar only to the branch in question. For instance, no book on steam engines would be complete without pipes and pipe joints, yet the latter would be equally essential to water or gas engineering." The introductory sections entitled "The Art of Technical Translating" and "Alternatives, Refractory Idioms and Peculiar Phrases" contributed by the editor, Ernest Slater, are sound and interesting, and there are other special features.

Another more specialised dictionary on this plan is that prepared by the Intelligence Division of the Naval Staff and published by H.M. Stationery Office in 1924 under the title *A Dictionary of Naval Equivalents*, which covers English, French, Italian, Spanish, Russian, Swedish, Danish, Dutch and German. Volume I has 362 pages, each containing about 20 expressions in all these languages, while Volume II contains a separate alphabetical index for each language (other than English which is covered by the arrangement in Volume I); the price is three guineas for both volumes. The terminology covered is not strictly confined to naval work but contains many useful equivalents in relation to shipbuilding and marine engineering generally.

The *International Electrotechnical Vocabulary* (London: International Electrotechnical Commission, 1938), price 10*s*., consists of a single foolscap volume of 311 pages and is arranged in sections by subject matter. Definitions of the terms in two to ten lines each are given in French and English in parallel columns and the terms themselves are stated also

in German, Italian, Spanish and Esperanto, with indexes at the end.

The *International Directory of Aviation* (Geneva : Interavia) includes a vocabulary of about 5,000 trade terms in English, French, German and Spanish.

Part I of a small *Dictionnaire International de Fonderie* (Paris : Association Technique de Fonderie) appeared in 1938 containing explanations in French of 829 foundry terms and indexes to them in French, American English, English, Spanish, Italian, Polish, Portuguese and Czech.

Another small dictionary on this plan, including definitions of the terms, is the *Technical Dictionary of Road Terms in Six Languages* (Danish, German, English, Spanish, French, Italian) compiled by the Permanent International Association of Road Congresses, Paris (1931).

The International Association for Bridge and Structural Engineering, Zurich, embarked in 1939 on the publication of a German-French-English vocabulary of these branches of engineering, incorporating a first instalment which had appeared in the *Stahlbau-Kalender, 1938* (Berlin : Ernst).

The *Glossary of Technical Terms as Used in the Metal Industry* in German, English, French and Italian (London : Cassier, 1938) was developed from lists originally compiled by the British Aluminium Co. Ltd.

If the principle of having to look up everything twice is accepted, its logical development is that adopted in the *Polyglot Dictionaries*, of which one volume (General Technical Terms) in English, and corresponding volumes in French, German, Dutch, and Italian, have been published at 6*s*. each by Technical Press, Ltd. Each volume refers to one language only and is divided into two separate halves, the first half containing words arranged alphabetically and

giving index numbers which will be common to all languages, the second arranged in order of the index number and giving the words in the language covered by that particular volume. Thus the user need purchase only those languages and those subjects which he needs. The above mentioned were intended as forerunners of other subjects and languages but are now out of print, and the publishers do not know whether publication will be resumed.

(3) A third type of technical dictionary is similar to (2) except that it contains illustrations in which the significance of every term is indicated—a merit which in my opinion more than compensates for the nuisance of double reference, because (if I may harp on this once again) it educates instead of short-circuiting the translator's mind. The best-known example of this is the *D–S Series of Technical Dictionaries in Six Languages* (English, Spanish, German, Russian, French, Italian), published as regards this country by Constable & Co. Since 1906 altogether 17 volumes have appeared, subdivided by subject matter so as to cover a very wide range of engineering and manufactures and varying in price from 10*s.* 6*d.* for Internal Combustion Engines to £5 for Electrical Engineering.

More recent volumes continuing the same series as the above but larger in format have appeared under the title *Illustrated Technical Dictionaries in Six Languages*, published by the V. D. I. Verlag in Berlin and distributed in this country by Lewenz and Wilkinson, Ltd. As an example Volume II may be mentioned ; this being a revised edition on Electrical Engineering and Electrochemistry with 1,304 pages and 3,965 illustrations, which appeared in 1928 and is priced at £4. The cost of its preparation is stated in the preface to have been in the neighbourhood of 500,000 gold

marks, provided by the German Government jointly with various scientific and engineering societies.

The *Guides Techniques Plumon : Dictionnaires Méthodiques Illustrés*, published by Beranger of Paris and Liége, are somewhat similar in plan though less ambitious and may be worth mentioning because those of them which are in six languages include Dutch among these (instead of the Russian in the aforementioned). As an example, Volume 26 (Tome II) deals with Bridges and Roads in six languages ; it was published in 1922 and contains 735 pages, priced at 7*s.* 6*d.* only. It was intended to produce eventually 40 of these vocabularies in two or more languages.

The same principle, but sometimes omitting the sketches, is followed in the *Illustrated Technical Dictionary* for those fields of technology which are covered by the Permanent International Association of Navigation Congresses. This has sketches on the left-hand page, and parallel columns giving the French, German, English, Spanish and Dutch words corresponding to the sketches on the right-hand page. Its compilation was agreed upon internationally, within the Association, in 1932, and each chapter is to be published as soon as it is ready. So far three chapters are available, dealing respectively with Fixed and Movable Weirs, Locks and Dry Docks, and Maritime Signals ; that on Ports was to follow, and in each case the subject matter relates rather to maritime and river engineering than to navigation in the narrower sense.

These notes on technical dictionaries are far from complete as they refer merely to some of those which happen to have come to my notice. A document known as *Bibliographical Series No. 256*, which is a catalogue of the 188 " Technical Glossaries and Dictionaries—English, Foreign and Interlingual ", available in the Science Museum Library,

South Kensington, can be obtained gratis on application. See also the book by Roberts quoted on page 200.

In 1941, the British Council allocated £2,000 for the translation of British Standards (regarding which see page 161) into Turkish, and several such translations have since been issued.

The following dictionaries of type (2) came to the author's notice after the above was already in page proof:

H. Oelschlaegel: *Trade Dictionary of Precious Metals, Gem Stones, Jewellery and Horological Products* (The Hague: Mouton & Co., 1939) is a work of 838 pages connecting French, English, German, Italian, Spanish, Portuguese, Czech and Dutch.

The *Swedish Export Directory*, 1946, published by the General Export Association, Stockholm, is a list of exporters of 3,081 industrial products, including machinery, in Swedish alphabetical order of the latter, giving under each the English, French, Spanish, German and Russian equivalents, with separate indexes from these languages.

CHAPTER TEN

THE TECHNICIAN AS A PERSON

INTRODUCTION

THIS short chapter is mainly to supply a few additional remarks and references which may assist those readers whose interest lies in the possibilities offered by careers in occupations dependent on technical knowledge.

Such occupations, whether wholly or only partly technical and whether "professional", commercial or ancillary to these, are so numerous and varied as to offer scope for a wide diversity of tastes, temperaments and aptitudes. The reader who has reached this point will, indeed, be under no delusion that "engineer" or "scientist" means one thing and one thing only, and will recall also some of the many other kinds of technician or part-technician whose existence has been mentioned or implied in these pages—administrators and business men; draughtsmen, quantity surveyors, cost accountants, time study experts; writers, abstractors, translators and interpreters; journalists and publishers; patent agents, examiners in the Patent Office [1] and barristers practising at the patent bar; surveyors to the classification societies and insurance companies; secretaries and staffs of

[1] Examiners in the Patent Office are civil servants admitted usually by competitive examination; patent agents are private practitioners who after serving a pupilage take a similar series of examinations conducted by the Chartered Institute of Patent Agents covering applied mechanics, chemistry, electricity, technical drawing, and actual work on specifications. In both cases women are eligible.

scientific institutions of every kind ; professors and teachers in technical colleges ; librarians and indexers.[1]

Nor does this list claim to be either logical or exhaustive.

INDUSTRY'S REQUIREMENTS IN PERSONALITY

Speaking on this topic at a conference on " Industry and University Education ", organised by the Imperial College in December 1945, Dr. Percy Dunsheath made the useful generalisation that most university students of engineering or science specialise ultimately in one of the four fields : Research, Design, Production or Teaching. He deprecated the tendency " to claim Research as the most suitable and the most lucrative goal for the bright student ", and urged the importance of guiding into each of these branches the most suitable kind of personality, which he distinguished as follows :

> In Research we want men who are insistent on self-discipline, men who are meticulously curious and observant of small distinctions . . . with a natural call to study and an inborn spirit of inquiry. . . . Never . . . those not suited to its continual disappointments. . . .
>
> In Production there is great scope for the best students, but here a broad human outlook is most important, a co-operative spirit. The Production Engineer not only must induce hundreds, perhaps thousands, to work efficiently and happily ; he must always be ready to take advice from Research and Design Departments.
>
> Design is midway between Research and Production in its call on human relations. It retains a good deal of the individualism of Research while ensuring practical day-by-day contacts with the producers.
>
> Finally, a word on the Teachers. Even from the industry I would

[1] The University of London School of Librarianship provides training useful not only for library work but for other branches of documentation also. See also page 223.

say that this is the highest of the four callings, a fact not sufficiently realised. Teachers cannot teach for industry without some knowledge of industry. . . . The senior university teaching appointments should carry salaries and prestige equivalent to senior industrial jobs.

EDUCATION AND TRAINING

To achieve competence in any of these kinds of work it is necessary to combine (*a*) the appropriate kind of technical knowledge with (*b*) ability to regulate one's own work in satisfactory relation to the people around one. In none of them is the technician a recluse cultivating knowledge *per se* ; but the relative importance of the technical and the human side varies greatly from one occupation to another and, within any given occupation, from one job to another. Vocational selection and preparation should be planned accordingly.

The preparation for and entry upon a technical career fall into three fairly well-defined phases :

(1) General education or "preparation for complete living" : a function whose importance it is impossible to exaggerate since if this is faulty whatever may be superadded will be stunted. Here supervised studies as well as liberal reading, games and sports, travel and languages, social intercourse, the initiation of hobbies and cultural interests, all have their parts to play : but the accumulation of specific knowledge is unimportant compared with disciplinary exercises to make the mind supple, independent and vigorous ; to develop clear thinking and clear expression ; to practise the art of seeking out and digesting knowledge on any subject as occasion arises ; to balance the mental with the physical powers ; and to afford preliminary experience in team working and in the conduct of human

relationships under conditions where mistakes will do no permanent harm.

"Education"—as Sir Richard Livingstone remarked—"is what remains after we have forgotten all we have learned." "The lowest form of knowledge"—another writer has said—"is the knowledge of facts." In this sense it matters less that what is taught should be useful than that it should play its part in integrating the character; yet nothing must be taught which afterwards has to be unlearned.

The normal place for education of this kind is at school, sometimes extended with advantage in the extra-vocational side of university work and life. It is a moot question how far specialised training ought to take the place of general education, and it may be a point in favour of the older universities that the substitution is less marked there than at the new.

(2) Specialised technical training is normally provided by way of three- or four-year courses in engineering or in other appropriate branches of science leading to the bachelor's degree of a university or to the diploma or certificate of an independent college. The training, not the degree, is the important thing, and by no means all engineers even of the highest standing are hall-marked in this particular way, some maintaining that theoretical knowledge is best acquired by private study or in evening classes concurrently with practical work as described under (3) below, leading, perhaps, to one of the National Certificates [151·2] or to an "external" degree of the University of London. There is great diversity in the conditions and nomenclature of the degrees in engineering granted by the 20 odd universities in the British Isles and a valuable series of articles on the subject by T. W. Chalmers, as well as a leading article and correspondence, appeared in successive numbers of *The*

Engineer from 2 November to 7 December 1934.[1] More detailed particulars of the courses and scholarships available are given in the " Calendars " which may be obtained direct from the respective colleges, in addition to which many of the professional institutions named in this book issue information indicating how the academic courses are related to their particular requirements for membership. Those prospectively interested should not fail to make as wide a survey as possible of the available facilities so as to ensure awareness of any special or local provision that may be advantageous in their particular circumstances or for the particular kind of career they have in mind, and this applies also to the semi-technical occupations given in the list above.[2]

(3) Transition from academic to practical qualification. This is the least formalised stage in the entry of a young engineer or scientist on his career but may be regarded as culminating in his admission to associate membership of the appropriate institution (see page 141 (*e*)). In mechanical and electrical engineering a works apprenticeship lasting several years is the usual procedure; opinion still differs as to

[1] Since republished in booklet form by *The Engineer.*

[2] See, for instance, the *6d.* booklets on many branches of engineering and industry in the " *Your Start in Life* " *Series* (London : G. Rivington Publications Ltd.) and those in the *Choice of Careers Series* of the Ministry of Labour ; also the articles in past issues of the *Journal of Careers* (London : Truman and Knightley Ltd.). A booklet entitled *Civil Engineering as a Career* has been issued by the Institution of Civil Engineers. There is a larger book by C. L. H. Humphreys and G. H. Humphreys : *The Training of a Civil Engineer* (London : Arnold, 1932). *The Public and Preparatory Schools Year Book* (London : H. F. W. Deane & Sons) contains eighteen pages of useful information on the engineering professions. As regards chemistry see [93.2]. On metallurgy see R. S. Hutton : The training and employment of metallurgists. *Inst. of Metals Monthly Journ.*, Vol. 4, Part 12, 1937 ; also J. G. Pearce : Foundry education and training in Great Britain, Paper No. 686 at Internatl. Foundry Congress (Inst. of Br. Foundrymen), June 1939, abridged in *Engineering*, 28 July 1939.

whether this should precede, follow or (as in Scotland) be "sandwiched" with the university course, but on the whole it seems to be thought better that the works training should come after the other and this may enable it to be shortened. In civil engineering the older system is still occasionally followed of dispensing with a separate university course in favour of articled pupilage to an engineer established in consulting practice, but it is more usual now for young graduates to obtain junior salaried posts or to become "trainees", "cadets" or "assistants under agreement" for the period of years necessary to qualify. Many firms and Government departments provide definite trainee schemes for engineering graduates, and the following list of these (not revised since the war) is reprinted by permission from a pamphlet issued by the Appointments Board of the Imperial College of Science and Technology :

Admiralty.	Vacation courses for those who intend to follow career of Naval Architect.
Allen, W. H., & Sons, Ltd.	Three years' Postgraduate Works Pupilage after completion of Degree course.
Automatic Telephone & Electric Co. Ltd.	For graduates taking up Communication (Telephony) Engineering.
Babcock & Wilcox, Ltd.	Student Apprenticeship for Engineers ; Vacation and Graduate courses.
Bristol Aeroplane Co.	Student Apprenticeship for Engineers.
British Broadcasting Corporation.	(i) Summer Vacation employment. (ii) Graduate course in Engineering.
British Thomson-Houston Co. Ltd.	(i) Student course for Graduates in Engineering. (ii) Vacation course.
Brown (David) & Sons, Ltd.	Two-year course for Graduates in Mechanical Engineering.
English Electric Co. Ltd.	Student apprentices—for those with degree in Engineering, Mathematics, or Physics.

General Electric Co. Ltd.	Two-year course for Electrical Engineers or Physicists.
Hackbridge Electric Construction Co. Ltd.	Postgraduate course—12 months.
Harland Engineering Co. Ltd.	(i) Vacation course extending over three years. (ii) Graduate course—three years.
Lancashire Dynamo & Crypto Co. Ltd.	Graduate courses in Electrical Engineering covering two years.
Mather & Platt Ltd.	Graduate courses in Engineering, two to two and a half years.
Metropolitan - Vickers Electrical Co. Ltd.	Courses in Engineering, and Postgraduate training of Chemists, Physicists and Metallurgists.
Metropolitan Water Board.	Premium and non-premium graduate pupils in Engineering.
Parsons, C. A., Ltd.	For Graduates in Mechanical and Electrical Engineering—two years' course.
Perkins, F. & Co. Ltd.	For Graduates in Mechanical Engineering—two years' course.
Reynold & Coventry Chain Co. Ltd.	For Graduates—three years.
Rheostatic Co. Ltd.	Electrical Engineering or Physics—two years' training.
Rolls-Royce, Ltd.	For Engineers—two or three years' training.
Royal Arsenal, Woolwich.	Student Apprenticeships—for Graduates in Engineering—three years' course.
Standard Telephones & Cables, Ltd.	For Graduates in Electrical (Radio) Engineering, Physics or Chemistry.
Thames Board Mills, Ltd.	For Engineers or Chemists—three years.
Unilever, Ltd.	For those possessing such qualifications as will, after special training and experience, be likely to fit them for responsible positions. Three years' course.
United Steel Companies, Ltd.	Graduate course (Scheme "B") of two years—Engineering, Physics, Chemistry.

The Imperial College also operates, through its Vacation

Work Committee, a scheme to assist students of that College (regarding whose constitution, see page 351) to obtain practical experience during their vacations. During 1943 over 200 firms co-operated in this.

Opportunities to proceed straight from school to a works apprenticeship exist in many engineering and industrial firms, both with and without the payment of a premium, and (as already mentioned) there are those who advocate this procedure apart from any question of finance. In considering such opportunities the important thing is to make sure that a sufficiently wide and well-balanced practical training is accompanied by facilities for pursuing theoretical studies without too great a personal strain.

A system of scholarships founded by Sir Joseph Whitworth exists for the benefit of works apprentices of not less than 30 months' standing who compete in an examination of the knowledge they have acquired by part-time study in order to proceed to a university. Whitworth Scholarships are worth £150 a year for three years and Whitworth Senior Scholarships (for which the examination is of degree standard) £300 a year for two years. They are administered by the Board of Education and the relevant *Regulations* may be obtained from H.M. Stationery Office, price 3*d.* Apart from the universities and colleges themselves some other bodies, such as the Institution of Naval Architects, award scholarships, and industrial concerns are beginning to do so: see page 89.

In this connection it might be worth while to consider the alternative of enlistment for a period of years in one of the technical branches of the armed forces, whereby a young man may combine good and progressive experience in some branch of engineering with an ampler way of life than is likely to come within his reach as an apprentice living

in cheap lodgings, and also with educational opportunities useful, if he so desires and has the ability, as stepping-stones to a professional status.

SPECIALISATION AND THE USE OF LEISURE TIME

The old adage that the most useful man is he who knows "everything about something and something about everything" was never truer than in these days of increasing specialisation within every profession—a specialisation rendered inevitable not only by the economic urge upon employers to make the most efficient use possible of their personnel but by the ever-growing range and variety of technical knowledge itself.

The present book may, it is hoped, prove helpful as an introduction to the art of collecting knowledge from fields collateral with one's own, with a view to fulfilling the second part of this adage. It should be realised, also, that its two parts are not antagonistic but complementary: for one cannot be a good specialist without being able to see one's speciality against a broad general background, and, on the other hand, there was wisdom in the words of the late Lord Stamp when he expressed himself as tired of people who lay claim to general culture without having themselves undergone the discipline of fine performance in some particular.

It is open to the technical man who feels that his daily work is too specialised or makes less than the full demand on his powers in the directions that attract him to redress the balance by private work in his leisure time. He may, for instance, study in this way to complete his professional qualification or to extend his skill in new directions,[1] or he

[1] For this purpose correspondence courses are excellent. I know of an engineer who learned reinforced concrete design by spending his evenings in that way whilst living alone in the depths of the Malay jungle.

may engage in some line of collative research with a view to a paper before an institution or conference or a thesis for a higher degree. The more experienced man may find opportunities where his services will be welcomed on committees. A linguist may be able to find an instructive and fairly remunerative hobby in technical translating. The preparation of abstracts for publication as discussed in [216·3] provides an unequalled means of keeping up with the literature of some branch of science while at the same time obtaining practice in the art of concise expression without the encumbrance of having also to invent things to express.

ASSOCIATIONS CONCERNED WITH CONDITIONS OF WORK

The professional institutions discussed in Chapter Four are preoccupied largely with the impersonal functions enumerated at the beginning of the list on page 141, and their ability to stand for scientists or engineers as such, in the way that the British Medical Association and the Law Society do for the medical and legal professions respectively, is hampered by the diversity of branches into which scientific and engineering work is divided. These facts have given rise to two organisations of a kind different from the aforementioned: the Association of Scientific Workers which has for its main objects "to promote the interests of the Scientific Worker and to secure the wider application of science and scientific method to the welfare of society" and The Engineers' Guild (founded in 1938)[1] which, similarly, "is an association of the Engineering Profession concerning itself with the status and interests of the pro-

[1] In 1945 an enquiry directed to the pre-war address of The Engineers' Guild elicited no reply.

fession and thus supplementing, but by no means competing with, the Engineering Institutions". In both cases membership is confined to qualified persons and it is sought to unify and support the activities of existing organisations in safeguarding the ethical standards and social conscience of the professions concerned by devoting more effective study to these relationships than is possible within the sectional institutions. The Association of Scientific Workers, which now has a membership approaching 17,000, publishes a monthly journal, *The Scientific Worker*, from which several references have been quoted here. A book giving the Association's policy for the future of Science is in preparation.

The British Association of Chemists and the Association of Engineering and Shipbuilding Draughtsmen are trades unions. The latter has a technical side which does some excellent publishing work.

SALARIES

The conditions of employment of qualified scientific workers other than engineers are critically reviewed by Professor Bernal in Chapter V of his book [76.1]. He quotes figures from an investigation by the Association of Scientific Workers which show that the average salary rises fairly uniformly from £245 a year for the age group 20–24 to £800 a year for the group 50–59, being at all stages distinctly higher in industrial than in academic work, only the full professors reaching an average in excess of £1,000. "It is probably true that for equal ability a scientific worker could add 50 per cent or more to his salary in other fields of enterprise, but for this loss he is supposed to be compensated by the agreeable nature of his work."

The old students' association of what is now the City and Guilds Engineering College made a similar investigation of

the salaries of civil, mechanical and electrical engineers, and the resulting statistical analysis shows a rise in the average from £100–£150 at the end of the first year after graduation to £500–£600 at the end of the tenth year.[1] This includes some engineers working abroad who receive higher salaries than are usual at home, but the openings for these are now far less numerous than formerly—which is a pity, as there was no better way of obtaining experience in a responsible position, not too specialised, at an early age.

The upshot of these indications, as of one's own impressions, is that the business of purveying and applying technical knowledge is not in itself a lucrative one, and that those to whom this is the governing consideration would do well to regard it only as an adjunct to other pursuits. But there are others to whom such a career is its own reward.

[1] Report and Discussion: The first ten years after leaving college. *The Central*, Dec. 1937, pp. 120–59.

APPENDIX

ABBREVIATIONS FOR ENGINEERING QUALIFICATIONS

and a few other technical qualifications

A.C.G.I. . . .	Associate of the City and Guilds Institute. (Diploma, equivalent to a degree, granted by the City and Guilds Engineering College.*)
A.R.C.S. . . .	Associate of the Royal College of Science.*
A.R.S.M. . .	Associate of the Royal School of Mines.*
	**These three colleges together constitute the Imperial College of Science and Technology, South Kensington.*
A.R.C.Sc.(I.). .	Associate of the Royal College of Science of Ireland.
A.R.T.C. . .	Associate of the Royal Technical College, Glasgow.
B.A.	*Baccalaureus in Arte:* at Oxford and Cambridge this is the degree ordinarily obtained in engineering as well as in other studies, the B.Sc. at Oxford and the M.Sc. at Cambridge being research degrees to which a B.A. may proceed. At Dublin a B.A.I. (see below) has first to take the B.A. degree which, as in most other universities, implies non-technical studies.
B.A.I.	*Baccalaureus in Arte Ingenieria:* the usual engineering degree at Trinity College, Dublin. (Similarly M.A.I.)
B.C.E., B.E.E., B.Mech.E., B.Met.E. . .	Bachelor of Civil, Electrical, Mining, Mechanical, Metallurgical Engineering in Melbourne University (4-year courses).
B.Eng.Sc. . .	Bachelor of Engineering Science, Melbourne University (3-year course).
B.E.	Bachelor of Engineering at other Australian universities and at certain Irish colleges.
B.Eng. . . .	Bachelor of Engineering at Liverpool or Sheffield.
B.Met. . . .	Bachelor of Metallurgy.
B.Sc.	Bachelor of Science, including the engineering degree at most universities.
B.Sc.(Eng.) . .	The London degree in Engineering as distinct from Science.
B.Sc.Tech. . .	The engineering degree at Manchester Municipal College of Technology, *or* the degree in Fuel Technology or Glass Technology (not Engineering) at Sheffield.
B.Tech. . . .	Degree in *Mechanical* Engineering or Industrial Chemistry in the University of Wales.
D.I.C. . . .	Diploma of the Imperial College of Science and Technology (for two years of advanced work, not necessarily research).

Dip. A.A.. . . .	Diploma of the Architectural Association.
Dipl.Ing. . . .	*Diplom-Ingenieur:* German equivalent of B.Sc.(Eng.).
D.Litt.. . . .	Doctor of Letters: in Scottish universities engineering graduates may, under certain conditions, proceed to this higher degree.
Dott. Ing.. . .	*Dottore Ingegnere:* Italian higher qualification.
Dr.Ing. . . .	*Doktor-Ingenieur:* German higher qualification.
D.Sc.	Doctor of Science: see page 84. Likewise D.Eng., D.Met.
Ing.	*Ingénieur:* French qualification sometimes followed by the initials of the engineering school at which obtained.
Ing.	*Ingegnere:* Italian qualification.
Ir.	*Ingenieur:* Dutch qualification.
M.A.	Master of Arts. In Scottish universities this takes the place of B.A. At Oxford and Cambridge B.A.s of some years' standing can obtain it by paying a fee. Elsewhere it involves research work in Arts subjects on a par with M.Sc.
M.P.S. . . .	Member of the Pharmaceutical Society of Great Britain.
M.Sc.	Master of Science: see page 84.
Ph.B.	Bachelor of Pharmacy at certain universities.
Ph.C.	Pharmaceutical Chemist Higher qualification of the Pharmaceutical Society, equivalent to B.Pharm.
Ph.D.	Doctor of Philosophy: see page 84.
V.D.I.. . . .	Verein Deutsche Ingenieure (German Association of Engineers).
Wh.Ex., Wh.Sch.	Whitworth Exhibitioner, Whitworth Scholar (for engineering studies). See page 346.

A.—— . . .	Associate of the——	*Institutions or Societies abbreviated as below where applicable*
A.M.—— . .	Associate Member of the——	
Comp.—— . .	Companion of the——	
F.—— . . .	Fellow of the——	
G.—— . . .	Graduate of the—— (A junior grade in some institutions, intermediate between Student and A.M.——)	
M.—— . . .	(Full) Member of the——	
P.P.—— . . .	Past President of the——	
Stud.—— . .	Student member of the——	

G.S.	Geological Society.
I.C.	Institute of Chemistry.
I.C.E.	Institution of Civil Engineers.
I.Chem.E. . .	Institution of Chemical Engineers.
I.E.E. . . .	Institution of Electrical Engineers.
I.H.V.E. . . .	Institution of Heating and Ventilating Engineers.
I.Mar.E. . . .	Institute of Marine Engineers.
I.Mech.E. . .	Institution of Mechanical Engineers.
I.Min.E. . . .	Institution of Mining Engineers.
I.M.M. . . .	Institution of Mining and Metallurgy.
I.Loco.E. . . .	Institution of Locomotive Engineers.
I.Mun. & Cy.E. .	Institution of Municipal and County Engineers.
Inst.P. . . .	Institute of Physics.
I.P.T.	Institution of Petroleum Technologists.
I.R.I.	Institute of the Rubber Industry.
I.Struct.E.. . .	Institution of Structural Engineers.
P.W.I.. . . .	Permanent Way Institute.
R.Ae.S. . . .	Royal Aeronautical Society.
R.G.S. . . .	Royal Geographical Society.
R.I. . . .	Royal Institution of Great Britain.
R.I.A. . . .	Royal Irish Academy.
R.I.B.A. . . .	Royal Institute of British Architects.
R.S.	The Royal Society.
R.San.I. . . .	Royal Sanitary Institute.
R.S.E.. . . .	Royal Society of Edinburgh.
S.C.I.	Society of Chemical Industry.
S.E.	Society of Engineers.
S.I..	Chartered Surveyors' Institution.
T.P.I.	Town Planning Institute.

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Experimental organisations (*see* page 81) and Collative organisations (*see* page 140) are mostly not indexed by name but under the subjects with which they deal, followed by E or C as the case may be.

Dictionaries are indexed under their special subjects followed by italic initials indicating the foreign languages they connect with English (*F* = French, *G* = German, *I* = Italian, *Pol.* = Polish, *Port.* = Portuguese, *R* = Russian, *S* = Spanish). Where several languages are combined in a single dictionary the initials are joined by hyphens.

Abstracts and bibliographies are listed under subjects on pages 206–7.

In all these cases it should be remembered that minor subjects, whether or not also mentioned separately, may be included in the scope of the major.

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